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Physical and Virtual Laboratories in Biochemistry Education

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Laboratory exercises and experimental work traditionally play a very important role in all scientific educational programmes at different levels of education. In chemistry and biochemistry there is a long tradition of including laboratory practicals in higher education. Bringing such experiences virtually is not an easy task, however education-technology researchers have been making substantial progress over the past decade.

Generally traditional practical work in the lab is very costly to implement due to specialized equipment, materials and laboratory instruments. In a physical lab, laboratory procedures are often dangerous and time consuming. Years ago, in 1990 Lagowski J (Editor of *Journal of Chemical Education*) referring to lab work notes: The expository laboratory satisfies the need to minimize resources particularly time, space, equipment and personnel [1].

It is known that internet and computer technology, interactive animations and virtual reality have a great impact on laboratory teaching and learning. Advanced computer-based technology and virtual simulations have changed the whole landscape of traditional lab on student laboratory learning, emphasizing the importance of learners taking an active role in their own learning [2]. A lot of studies in literature present data on virtual and hands-on learning process.

The categories of intended outcomes for laboratory learning as were designed by JR Brinson [3] and according to the National Research Council (NRC) goals of laboratory, are:

- Knowledge & Understanding- Enhancing mastery of subject matter
- Inquiry Skills
- Practical Skills
- Perception
- Analytical Skills
- Social & Scientific Communication

Virtual experiments based on computer technology enable students to conduct multiple experiments shortly allowing repetition and modification (changing parameters that are not possible in physical experiments) with on line help and guidance.

Virtual labs have also the advantages of low cost offering alternatives to traditional labs, it is becoming increasingly difficult and costly to maintain and support a laboratory with necessary and of high cost equipment.

There are many studies comparing the advantages and disadvantages of physical and virtual labs based on measures of different laboratory learning outcomes. Most studies measure only the conceptual understanding but the other learning outcomes have to be investigated. A lot of studies show that virtual labs are equal or exceed physical labs related to knowledge and conceptual understanding [2,4]. However other outcomes as practical skills in a traditional lab like handling of chemicals, use of biochemical instruments, deserve attention. So studies measuring as outcome the practical skills, show the advantages of a hands-on lab over a virtual lab. It must be emphasized that in some studies when students completed virtual labs and then the physical exercise practical, they performed better than students who carried out the practical in physical lab [3]. Also, there is an additional type of lab work in higher education, the remote lab which is a physical lab performing experiments over the internet.

However there is a continued unresolved debate over the effectiveness of different laboratory modalities in higher education. The fact that hands-on labs are becoming increasingly mediated (for example through a PC connected) deserves attention [5].

The existing disagreements among education investigators in the debate regarding the efficacy of virtual labs versus physical labs, are due mainly to the measure of learning outcome [3]. The concept of a "virtual lab" has to do with a set of features as of hypermedia (and hypergraphics), interactive animation, multimedia, model simulation for data visualization, the feature of hypertext, and the use of 3D virtual reality. Thus it is not trivial to mention the great didactic and learning potential of the virtual labs. The accompanying wikis, blogs and social media technologies support collaborative learning.

In every domain of higher education and learning *specific* didactic challenges are relating to the appropriate scientific content. Didactic problems are sometimes discussed in the context of pedagogical content knowledge [6], indicating that specific disciplines concerning teaching and learning play an important role.

Regarding biological chemistry and biochemistry, there are conceptual difficulties in learning procedure. Some difficulties are inherent to biochemistry while other difficulties arise from prior learning in general and physical chemistry and from supporting basic disciplines like physics. Conceptual difficulties inherent to biochemistry (and/or molecular biology) are usually problems in understanding enzyme-substrate interactions and kinetics and problems in visualization of complex protein structures. Also, there are difficulties in understanding specific instrument-based techniques and procedures [for example polymerase chain reaction (PCR), gel electrophoresis, enzyme-linked immunosorbent assay (ELISA)] [7].
Today there are many simulations in the fields of chemistry, biochemistry and medicine.

Labster's enzyme-kinetics simulation helps students to run experiments and learn all about the kinetics of an enzyme as if they are in a real laboratory [8].

Labster Virtual Lab: Enzyme Kinetics Simulation [8].
Image reproduced from https://www.labster.com/simulations/enzyme-kinetics/ with permission.
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Currently in biochemistry the scientific progress must follow advancements in technology and laboratories have to incorporate virtual simulations, bioinformatics and other computational tools supporting learning. In higher education, for example biological chemistry, medicinal chemistry, biochemistry and molecular biology, there is a need the students to be introduced to the drawing tools, simulation tools, wikibooks and on line databases (such as the PDB protein data bank). So we need to address these problems in the context of virtual labs simplifying understanding and learning procedures.

Skepticism and Future Research

With the advancement of educational technology, coupled with the increase of online education in all grades of education, virtual labs are becoming more interactive, manipulative and real. The existing debate about the efficiency of each lab modality in learning outcomes is the result of many intertwined factors which must be analyzed separately. The future of this technology is very promising.

Virtual experiments offer some advantages over hands-on experiments because they typically require less setup time and provide results instantaneously. This enables students to perform more experiments and thus have more information. Students through virtual labs perform and fail multiple times without cost using a great variety of variables and procedures regardless of their physical lab access, in a quick, cheaper and more efficient manner than is currently possible [9]. Virtual labs can be used for student's preparation for hands-on experiments. Also in case of unsafe and too costly experiments a virtual lab can substitute a physical experiment. An important issue in the success of science instruction is the guidance to ensure that students will benefit from laboratories [4,10].

Today with the explosive popularity of online learning, researchers are seeking new modes to teach the practical skills of science.

The virtual labs offer great flexibility and especially in massive open online courses (MOOCS) like Edx (founded by Harvard University and the Massachusetts Institute of Technology) where there is a future planning of mix-and-match components from lectures to lab simulations, customized to anyone's needs [11].

There are still fundamental differences between physical and virtual labs, of course.

It is doubtful whether virtual labs will completely replace traditional bench work in scientific educational programs just yet.

An interesting topic in this field is an approach known as the "blended" or "hybrid" approach to laboratory learning. In this approach, both hands-on and virtual modalities are combined in an attempt to maximize achievement of knowledge and understanding outcome using non traditional lab and the technical skills outcomes from physical manipulation in physical laboratory. Likewise, studies have also provided data supportive of blended labs being more effective than virtual labs alone [12]. For distance education science classes, the traditional component of this approach typically utilizes lab kits. Also many current science laboratory exercises involve computer and technological mediation during the process. From this point of view, a pure hands-on lab is rare. Therefore, we may really be discussing about relative degrees of hands-on, simulation, and remoteness. In fact most laboratory classes involve a combination of hands-on, computer-mediated, and simulation tools. With the implementation of blended learning approach there is economic benefit [3].

No consensus exists yet regarding the best practice. When virtual labs are strategically used in the right way, they can improve and enhance all kinds of learning outcomes. More, for those who have no access to traditional labs, a virtual lab is better than no lab at all. With the new technologies increasing we have to take advantage of virtual and online investigations studying further and analysing in detail.

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