Use of Virtual Labs in the Tertiary Education

Subjects: Education & Educational Research

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There is a growing demand for Virtual Laboratories (VLabs) in tertiary education to support remote, flexible, and equitable learning. Most of the universities in Australia offer distance education to students who do not attend on-campus classes. On-line labs allowing access via an internet connection can offer learners the required infrastructure to complete their lab tasks without attending physical lab facilities. The onset of COVID-19 pandemic in early 2020 has seen further spike in demand for VLabs as accessing online lab facilities to undertake hands on activities from anywhere and anytime was imperative during lockdown periods.

irtual labs ubiquitous learning e-learning learning theories

1. Introduction

There is a growing demand to support learners in the higher education sector with a diverse requirement of flexibility such as location, time zone, work hours. The onset of COVID-19 pandemic in early 2020 has re-instated this demand [1]. To facilitate such flexibility, ubiquitous learning (U-Learning) which allows learning to take place using any device in a flexible environment of time, place, and pace, needs to be adopted in the higher education sector [2]. U-Learning in the modern era can be supported through the adoption of e-learning which uses the Internet technology to deliver educational solutions to the learners, with the inclusion of networked systems, and a focus on the on-demand learning [3]. Bermejo et al. [4] reported e-laboratory being one of the most interesting solutions for e-learning, which provides students with the opportunity to put their theoretical knowledge to practice by using unlimited internet access to carry out their laboratory exercises on-line, while remote laboratories are physical facilities that are accessed over a network connection and related software [5], Virtual laboratories (VLabs) do not have physical facilities, rather virtual laboratory resources (e.g., hardware, software on the cloud) are accessed using an internet connection [4]. Because of the virtual nature of, and the remote access to, the laboratory resources, many users can access it at the same time, which represents the elasticity of the lab facility beyond what physical labs can offer.

For higher education students in Information and Communication Technology (ICT), the application of theoretical knowledge in practical tasks is essential in gaining the skills needed in the industry. For example, multidisciplinary practical subjects like ‘Digital Forensics’ or ‘Internet of Things and Cloud Computing’ are best taught using the Problem Based Learning (PBL) pedagogy [6][7]. In ‘Digital Forensics’ students examine digital data in search of criminal evidence in practical exercises whereas in ‘Internet of Things and Cloud Computing’, students need distributed networked sensors to learn and apply their skills in practical implementations [8] to achieve their unit learning outcomes (ULOs). Such activities for Digital Forensics require students from all learning modes, i.e.,

online as well as on campus (Face-to-Face), to access industry grade forensics laboratories (lab) with heterogeneous Operating Systems, licensed software (tools), hardware and systems with administrator level access. Such facilities are beyond the capacity of campus based general purpose computer labs which indicates that there is a need of providing special-purpose labs in campuses which has cost implications. Importantly also, using such (physical) labs to teach does not support the mentioned learning flexibility and equity for all modes of students. This creates inequity for online students who are unable to attend physical facilities. These hurdles can be overcome by using virtual labs in the ICT teaching.

VLabs have been providing practical lab experiences to students during the COVID-19 pandemic since access to physical labs may not exist or be restricted [9][10]. Educators across disciplines have recognized the value of VLabs for their students as VLabs provide flexible learning opportunities, a preparatory environment for physical labs, and collaboration opportunities [9]. The use of technology for accessing and working with VLabs is a bonus in making graduates ready for future employments, with their familiarity of using virtual training that are often used in workplaces [9]. However, the VLab needs to be designed appropriately based on the content and technology associated with the delivery. Furthermore, the VLab designs and case studies are not analyzed and argued using learning theoretical lens.

To help making an informed decision about the choice of VLab types, two VLab types have been presented, using case studies: commercial (or off-the-shelf) VLabs, and custom-made VLabs. Based on the use of both types of VLabs in tertiary education, the case studies present first the experience of using MindTap VLab which is a commercial VLab, and then a custom-made, purpose built VLab which was developed using cloud based resources. The case studies are guided by educational pedagogy, technology, design, and outcome of the use of VLabs in tertiary education context for ICT courses. The study has also detailed challenges associated with VLab implementation, which can be a great guide for educators to choose an appropriate VLab to support learning philosophy, pedagogy and most importantly learners to achieve best potential outcome.

2. The Use of Virtual Labs in the Tertiary Sector

Although the use of VLabs has seen a renewed interest during COVID-19 pandemic, VLabs have been used in the tertiary sector in various capacities in pre-Covid era too, specially in ICT [2]. With the proliferation of the internet-based applications used by general public, students from any discipline have familiarity of the online interfaces to use VLabs. Hence, during COVID-19 lockdown, many Australian universities have introduced VLab as a replacement of laboratory facilities, as used in many disciplines [9][10][11][12], to allow students complete their laboratory tasks.

Virtual Labs have been used in a range of non-ICT disciplines such as Biochemistry and Molecular Biology [9], Mechanical Engineering [10], Physics [11], Optics [12], and Rehabilitative Sciences [13]. The VLabs are used to complement onsite teaching in Optics [12], train the faculty members on mechanical engineering and student experiments on fluid mechanics [10]. Furthermore, the use of VLabs [10] have enhanced collaborative learning in Biological Sciences higher education [14]. These examples demonstrate VLab's utility even when learners could

attend in-person classes (e.g., during pre-Covid era). Virtual Labs are generally used to achieve discipline learning objectives (LOs), however, during the COVID-19 pandemic these have been used as an alternative to physical labs in various discipline offerings that did not use VLabs in the pre-Covid era. For example, Puzziferro et al. [13] presented their experience of delivering VLabs during COVID-19 pandemic for rehabilitation sciences in terms of strategies with instructional cases.

As a teaching tool in ICT discipline, VLabs have been used to achieve various learning objectives in general, as well as a replacement of physical laboratory during COVID-19 pandemic as was for any other discipline. Deng et al. [15] reported the use of a web-based personalized virtual lab environment in the undergraduate teaching of cybersecurity class at Arizona state university. Authors reported that the personalized lab environment enhanced student engagement, better understanding of assessments, and ultimately enhanced learning outcome. At the Central Queensland University Australia (CQUniversity), VLabs for teaching Computer Forensics, Cloud Computing, and Internet of Things (IoT) units (subjects) have been used to support our learners and to achieve learning outcomes. To ensure effective and catered learning flexibility and support, two approaches; custom-built (by the teaching team), and commercially available off-the-shelf VLabs have been taken .

Well-founded learning theories also support the use of VLabs to achieve more effective learning outcome. For example, according to Siemens et al. [16], learning is a process of developing a learning network and making connections between ideas of human (related with human cognition) which aligns with Vygotsky's constructivism theoretical paradigm, which has emphasized learning being a process instead of product and human interaction and symbolic tools were needed to achieve effective learning outcomes and solving critical problems. The VLabs are effective symbolic tools that are designed and supported by modern technology innovations in learning space. Therefore, it is important to discuss learning theories to understand how VLabs can be a teaching tool that is supported by learning pedagogy to ensure effective design and and learning experiences for learners.

3. Learning Theories

This sub-section detailed existing learning theories that have led to choose effective objects, tools and props to design the VLab. According to contemporary educational research, five major learning theories have been used in higher education classrooms: behaviorism, cognitivism, constructivism, humanism and connectivism [17]. The researchers have found different theories have emerged due to different kind of learning needs of the learners [18] and based on different settings of learning, for example, distance learning, experimental laboratory, school setup and workplace setup and so on. These theoretical lenses help teachers to model their learning strategies and to develop educational technologies to support learning goals. Therefore, the role and interactions around VLab were directed by existing proven practices established by learning theories in the literature. Furthermore, each of these theoretical perspectives play a role in describing how students learn. Each theory is quite different and explains learning in different ways. For example, while behaviorism, cognitivism, constructivism, and humanism are the core learning theories dominated of instructional environments, a more recently developed learning theory is connectivism which proposes that knowledge is distributed across a network of connections and, consequently, learning is the ability to construct and traverse those networks.

The traditional epistemological paradigms like Vygotsky's cultural-historical theory [19], Bandura's social cognitive theory [20], Bronfenbrenner's ecological system theory [18] and Leontiev's activity theory [21], have emphasized the social, situational, and relational aspects of knowledge and learning. The concept of "mediation" was first used in Vygotsky's cultural-historical theory where higher mental function was viewed as a mediated function [22]. Some of Vygotsky's colleagues and students pioneered and elaborated on their idea. Kozulin et al. [23] states that there are two types of mediation: human mediators and the symbolic (system) mediators. The design of the VLab has embedded both system and human mediation to support students interactions based on reactions collected in the form of systems data.

The importance of Vygotsky's cultural historical emphasized on human interaction to development of higher mental functions (problem solving, logical thinking, attention, abstraction and perception and so on.) in a dialectical way, where it has dynamic relations between the external and the internal level instead of linear [24]. Therefore, human interaction to develop higher mental functions is applicable on children's as well as adult's learning. Vygotsky [24] first used the term "psychological (symbolic) tool" to interact with people. According to Vygotsky, symbols can be categorized in two ways

- Using object and props (objective sense), and
- Interacting with humans (subjective sense).

Human intervention is needed to use these symbolic tools purposefully, otherwise, it will not make meaning in the learning process. For instance, the VLab cannot be a technological tool by itself unless the teacher (mediator) is designing it purposefully and guiding students' learning process to achieve their learning goal.

In the 21st century digital era, learning landscapes are network, social and technological based. The constructivist theory of learning emerged prior to the revolutions of information technology (IT), therefore new perspectives of learning theory have emerged which is connectivism. Similar with constructivism theory, Siemens and Dowens [25] connectivism theory emphasized on using of online tools (for example threaded discussion in Moodle, blog posts, second life and synchronous online meetings) to connect with learners. Several researchers found social media platform promoted connectivity, learners' engagement, collaboration and the development of professionalism [26][27][28], however, there are some challenges like technical problems, privacy issues that the teachers and students faced using this platform [26]. In the design of the VLab, the connectivism is integrated using virtual collaboration/engagement with LMS integration to foster discussion and flexible learning opportunity.

From constructivism theoretical perspective, VLabs can be a great platform for teachers to use as a tool (objective sense) for designing problem-based learning (PBL) based assessments for students to solve (subjective sense) using industry scale technologies. Based on constructivism theoretical perspectives George Siemens (2004) stated connectivism views learners should be developing a learning network and making connections between ideas embedded throughout that network. With the facilities available in the VLab setup, PBL have been designed based assessments to foster learning connections throughout the VLab resources.

Herein, it has used a blended approach to integrate connectivism to create opportunity for making connections between ideas with the help of object, prop and mediation (both human and symbolic) as stated in Vygotsky's theory.

References

1. COVID has Changed Students' Needs and Expectations. How do Universities Respond? The Conversation, 17 December 2021.
2. Gros, B.; Kinshuk; Maina, M. The Future of Ubiquitous Learning- Learning Designs for Emerging Pedagogies. Lecture Notes in Educational Technology. The Future of Ubiquitous Computing; Springer: Berlin/Heidelberg, Germany, 2016.
3. Rosenberg, M.J. E-Learning: Strategies for Delivering Knowledge in the Digital Age; McGraw-Hill Education: New York, NY, USA, 2000.
4. Bermejo, S. Cooperative electronic learning in virtual laboratories through forums. IEEE Trans. Educ. 2005, 48, 140–149.
5. Kurukunda, S.; Trigona, C.; Baglio, S. Laboratory Activity during COVID- 19 as a "Virtual Experience": Restriction or Chance? In Proceedings of the 2020 17th International Multi-Conference on Systems, Signals Devices (SSD), Sfax, Tunisia, 20–23 July 2020; pp. 349–353.
6. Bevinakoppa, S.; Ray, B.; Sabrina, F. Effectiveness of problem-based learning implementation. Int. J. Qual. Assur. Eng. Technol. Educ. (IJQAETE) 2016, 5, 46–58.
7. Ray, B.; Sabrina, F.; Bevinakoppa, S. Develop and Implement Problem Based Learning Exercise Exemplar for Post Graduate Units. In Proceedings of the 2nd International Conference on Engineering and Technology Education (ETE '15), Seoul, Korea, 20–22 September 2015; pp. 49–57.
8. Lang, A.; Bashir, M.; Campbell, R.; DeStefano, L. Developing a new digital forensics curriculum. Digit. Investig. 2014, 11, S76–S84.
9. Vasiliadou, R. Virtual laboratories during coronavirus (COVID-19) pandemic. Biochem. Mol. Biol. Educ. 2020, 48, 482–483.
10. Kapilan, N.; Vidhya, P.; Gao, X.Z. Virtual Laboratory: A Boon to the Mechanical Engineering Education During COVID-19 Pandemic. High. Educ. Future 2021, 8, 31–46.
11. El Kharki, K.; Berrada, K.; Burgos, D. Design and Implementation of a Virtual Laboratory for Physics Subjects in Moroccan Universities. Sustainability 2021, 13, 3711.
12. Gamo, J. Assessing a Virtual Laboratory in Optics as a Complement to On-Site Teaching. IEEE Trans. Educ. 2019, 62, 119–126.

13. Puzziferro, M.; McGee, E. Delivering Virtual Labs in Rehabilitative Sciences during COVID-19: Strategies and Instructional Cases. Online J. Distance Learn. Adm. 2021, 24, 136–139.
14. Manchikanti, P.; Kumar, B.R.; Singh, V.K. Role of Virtual Biology Laboratories in Online and Remote Learning. In Proceedings of the 2016 IEEE Eighth International Conference on Technology for Education (T4E), Mumbai, India, 2–4 December 2016; pp. 136–139.
15. Deng, Y.; Lu, D.; Chung, C.J.; Huang, D.; Zeng, Z. Personalized Learning in a Virtual Hands-on Lab Platform for Computer Science Education. In Proceedings of the 2018 IEEE Frontiers in Education Conference (FIE), San Jose, CA, USA, 3–6 October 2018; pp. 1–8.
16. Siemens, G. Connectivism: A learning theory fort he digital age. Ekim 2004, 6, 2011.
17. Kapici, H.O.; Akcay, H. Cognitive Theories of Learning on Virtual Science Laboratories. In Education Research Highlights in Mathematics, Science and Technology; ISRES Publishing: Ames, IA, USA, 2019; pp. 107–126.
18. Urie, B. The Ecology of Human Development: Experiments by Nature and Design; Harvard University Press: Cambridge, MA, USA, 2009.
19. Rieber, R.W.; Carton, A.S. The Collected Works of LS Vygotsky: Problems of General Psychology, Including the Volume Thinking and Speech; Springer: New York, NY, USA, 1987.
20. Bandura, A. Social Foundations of Thought and Action: A Social Cognitive Theory; Prentice-Hall, Inc.: Englewoods Cliffs, NJ, USA, 1986.
21. Leont'ev, A.N. The Problem of Activity in Psychology. Sov. Psychol. 1974, 13, 4–33.
22. Veresov, N. Introducing cultural historical theory: Main concepts and principles of genetic research methodology. Cult. Hist. Psychol. 2010, 4, 83–90.
23. Kozulin, A. Psychological tools and mediated learning. Vygotsky's Educ. Theory Cult. Context 2003, 4, 15–38.
24. Vygotski, L.S. The Collected Works of LS Vygotsky: The History of the Development of Higher Mental Functions; Springer Science & Business Media: New York, NY, USA, 1997; Volume 4.
25. Downes, S. Places to go: Connectivism & connective knowledge. Innov. J. Online Educ. 2008, 5, 6.
26. Cheston, C.C.; Flickinger, T.E.; Chisolm, M.S. Social media use in medical education: A systematic review. Acad. Med. 2013, 88, 893–901.
27. Hollinderbäumer, A.; Hartz, T.; Ückert, F. Education 2.0-How has social media and Web 2.0 been integrated into medical education? A systematical literature review. GMS Z. Med. Ausbild. 2013, 30, Doc14.

28. Ray, B.; Devi, A. Academic Debate on Using Social Networking Media: Teachers' and Students' Perceptions from Two Tertiary Institutions. Int. J. Learn. Teach. 2015, 1, 168–173.