education sciences

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Virtual Laboratories in Tertiary Education: Case Study Analysis by Learning Theories

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Abstract: This paper examines and evaluates Virtual Laboratories (VLabs) in consideration of technology design, educational pedagogy, and outcome in tertiary education context for ICT courses. There is a growing demand for 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. Despite their benefits, it is complex to choose an appropriate VLab design or type that ensures effective and improved learning process. This paper presents two case studies using commercial and custom-made VLabs that are analyzed through the lens of learning theories. The outcome of the analysis informs the readers that the teachers' support (human mediator) and VLabs (teaching tool) are interlinked together in a dialectical way which is an important consideration to achieve successful learning outcome. This study will help educators to make an informed decision in choosing an appropriate VLab design for their teaching content to ensure effective learning outcome.

Keywords: virtual labs; COVID-19; ubiquitous learning; e-learning; learning theories

Citation: Hassan, J.; Devi, A.; Ray, B. Virtual Laboratories in Tertiary Education: Case Study Analysis by Learning Theories. *Educ. Sci.* **2022**, *12*, 554. https://doi.org/10.3390/educsci12080554

Academic Editor: Maria Limniou

Received: 28 June 2022
Accepted: 8 August 2022
Published: 15 August 2022

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, this paper has presented two VLab types, using case studies: commercial (or off-the-shelf) VLabs, and custom-made VLabs. Based on our use of both types of VLabs in tertiary education, the case studies present first our experience of using MindTap VLab which is a commercial VLab, and then a custom-made, purpose built VLab which we 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. This paper 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.

The rest of the paper is organized as follows. In Section 2, we have provided background of the study where brief overview of VLabs in ICT and non-ICT teaching are detailed in Section 2.1 followed by a discussion on the learning theories in Section 2.2. In Section 3, we have presented case studies of commercial and custom-build VLabs in ICT tertiary education. We provide discussions in Section 4 followed by a conclusion in Section 5.

2. Background

Virtual Labs are a popular teaching tool in Australian universities. Their usage have dramatically increased in the last two years due to COVID-19 pandemic. Our motivation of using virtual lab is grounded by learning theories that helped us to design and utilize it as an effective learning tool. This section has detailed literature on the use of VLabs in various disciplines which is followed by learning theories to evaluate the use of VLabs in tertiary education sector.

2.1. 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 [9–12], 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), we have been using VLabs for teaching Computer Forensics, Cloud Computing, and Internet of Things (IoT) units (subjects) to support our learners and to achieve learning outcomes. To ensure effective and catered learning flexibility and support, we have taken two approaches; custom-built (by the teaching team), and commercially available off-the-shelf VLabs. We have elaborated both approaches, their motivation and design in Section 3.

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 we need human interaction and symbolic tools 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. In next Section 2.2, this paper has detailed learning theories to analyze VLab case studies under the lens of learning pedagogy.

2.2. Learning Theories

This sub-section detailed existing learning theories that have led us 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, etc. These theoretical lenses help teachers to model their learning strategies and to develop educational technologies to support learning goals. Therefore, our 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 our 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 etc.) 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 [26–28], however, there are some challenges like technical problems, privacy issues that the teachers and students faced using this platform [26]. In the design of our 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, we have been designing PBL based assessments to foster learning connections throughout the VLab resources.

This paper 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. In the next section, this paper has detailed two different VLabs design, such as commercial, and custom-built, along with their use cases analyzed based on learning pedagogy and outcomes.

3. Case Study

In this section, we have detailed the design, implementation, and outcome of the two VLabs, commercial (off-the-shelf) and custom-built, in Sections 3.1 and 3.2 , respectively.

3.1. Teaching Using a Commercial VLab

At CQUniversity, we have developed and teach computer forensics subjects (units) for both undergraduate and post graduate levels. These subjects integrate digital investigations though a legal lens which is an essential requirement for cybersecurity jobs in the industry. Our ICT students undertake these units in either face-to-face or online learning modes. Further, we do not have any residential schools for the online mode ICT students.

As mentioned in [8], we also realized that 'Digital Forensics' being a multidisciplinary and practical subject, is best taught using the problem-based learning (PBL) pedagogy [6,7] where students learn through undertaking hands-on digital forensics investigations. These investigations would require students to use industry grade, licensed digital forensics software (tools) to examine digital data using industry accepted processes, in search of criminal evidence. According to Vygotsky's theory [29], human development and learning cannot happen in a liner process, rather it must be viewed as a unity of the material world and the individual's internal mental aspect. This unity must be address as the real-life experiences where PBL pedagogy takes place through hands-on activities. To provide our computer forensics students an opportunity to engage in real life problem-based learning (PBL), in our initial offerings of the units, we used campus based general purpose computer labs with required forensics software installed on the computers to teach on-campus students. For on-line students, demo versions of the tools were installed on students' personal computers. We faced several challenges below with this setting.

- The forensics tools required students to have administrator level access to the host computers, which was not possible to allow in the campus based general purpose labs,
- On-line students faced the issue of licensing fees for the tools for full functionality,
- On-line students faced difficulty in downloading huge amounts of data required for the investigations, especially over slow internet connections,
- Most of the tools are not platform independent, running only on Windows Operating System (OS) computers, while some others only ran on Linux OS.

The above mentioned challenges led to a significant hindrance to learning: students missed having a comprehensive experience of working with the feature-rich tools across all OS platforms. The licensing requirement imposed additional barriers too. It was impractical to maintain licenses and updated versions of a plethora of forensic tools in the labs across multiple campuses, but the demo versions lacked functionality which was not a practical choice either. Further, the online and Bring-Your-Own-Device (BYOD) students would have to pay to install these tools on their computers. As a result, students could not fully engage with the practical lab tasks to develop their skills required for solving real-life investigative tasks. As such, the integration of industry grade forensic lab, with unrestricted access to a wide range of licensed forensics software and physical hardware with administrative access, would address hindrances such as (i) practical learning experience, (ii) student engagement, and (iii) equitable accessibility for all students.

We have addressed this by integrating a VLab Environment in the units. The VLab, detailed below, provides our students, of all learning modes, unrestricted access to industry grade forensic tools, hardware, and data to carry out practical exercises of forensics investigations.

MindTap: Cengage Learning's Virtual Lab

As mentioned previously, without teacher's intervention, tools will be perceived as a simple object rather than a learning tool that will be appropriated for use by the students [23]. For example, a computer will be a simple device or object and cannot be a teaching tool if the teacher is not using it purposefully for the learning process. We approached Cengage Learning [30] for a virtual digital forensic laboratory with widely used forensics tools. Out of a few demonstrated virtual labs, we have chosen MindTap virtual learning environment to customize for our syllabus and implemented it in our teaching. We have been using this VLab environment ever since for all of our forensic units. MindTap provides our students digital accessibility by using virtual forensic tool platforms.

Students get access to a virtual networked lab environment as shown in Figure 1 (source: Cengage Learning [30]), featuring multiple Virtual Machines (VMs) running various Operating Systems (OSs): PLABWIN10 is a standalone workstation running Windows 10, PLABDEFT01 is a Ubuntu Linux workstation, and PLABKSRV01 is a Kali Linux Workstation. Each virtual machine within MindTap VLab environment provides a specific OS interface (see Figure 1), and includes a wide range of forensics tools and data to carry out investigative tasks. This kind of VM setup with multiple OSs allows our students to work with wide range of data sources (data from various OS workstations) from suspects' computers, without requiring access to multiple physical computers running different OSs. The VMs provide a complete access to both digital forensics data and a range of industry-grade digital forensics tools that the students access to undertake investigations to discover forensics evidence. It fosters ubiquitous access to students studying in various enrolment modes, which caters well for online learning during COVID-19 pandemic, which is a recent bonus for our students. MindTap VLab environment, integrated in the LMS (e.g., Moodle), is more than a virtual lab, offering four different weekly modules as shown below that students can explore and learn from.

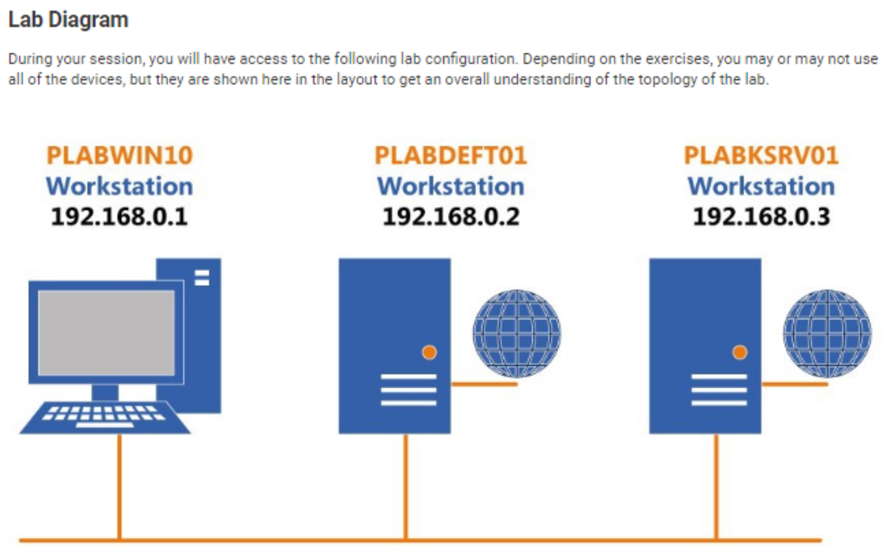

Figure 1. MindTap Virtual Machine (VM) Lab network diagram.

- Live virtual machine (VM) labs activities: this is an interactive learning environment where students can practice their problem-solving skills on live IT systems in real time. To create virtual labs, hardware and virtualization techniques are necessary, which for the live VM labs have been implemented using Cisco hardware and virtualized operating systems of Windows, Linux, and UNIX. The virtual operating systems are hosted on VMware and Hyper-V, creating virtual machines, that are accessible via a web browser [31].
- Study module to learn the theoretical concepts: this provides students an opportunity to review the main concepts on the weekly topic.
- Apply module to practice the learned concepts: this provides a set of quizzes that students take to test their learning on the weekly topic. Students receive instant scores for their completed quiz, and feedback on any incorrect answers, whereas the instructors can see the their class performance on the quizzes.
- A news module: this provides access to latest digital forensics magazine articles, news items, blog posts and RSS feeds.

The integration of MindTap VLab into the units' LMS websites allows students' to access it by using their internet connections and a web browser, from anywhere, anytime. This has provided an effective environment to students across learning modes to engage with real-world practice tasks using digital data and hardware located on the VLab environment (no downloading needed), and unrestricted access to a range of industry grade forensic tools. Figure 2 illustrates the Windows 10 virtual machine interface within MindTap environment which hosts a range of forensics tools and data. Students are able to access additional learning resources on the VLab Environment including practice tests through the unit LMS website. As illustrated in Figure 3 (source: Cengage Learning [30]), student can use a specific forensic tool and investigate using data located on the VM. Students can download or upload data to and from the VM and the local computer while a specific tool being used in this environment. As per constructivist epistemology, in this integrated VLab environment, students own the problem and understand/accept learning objectives and they control the problem solving process [32]. The VLabs give them scope to learn from real experiences by using learning resources.

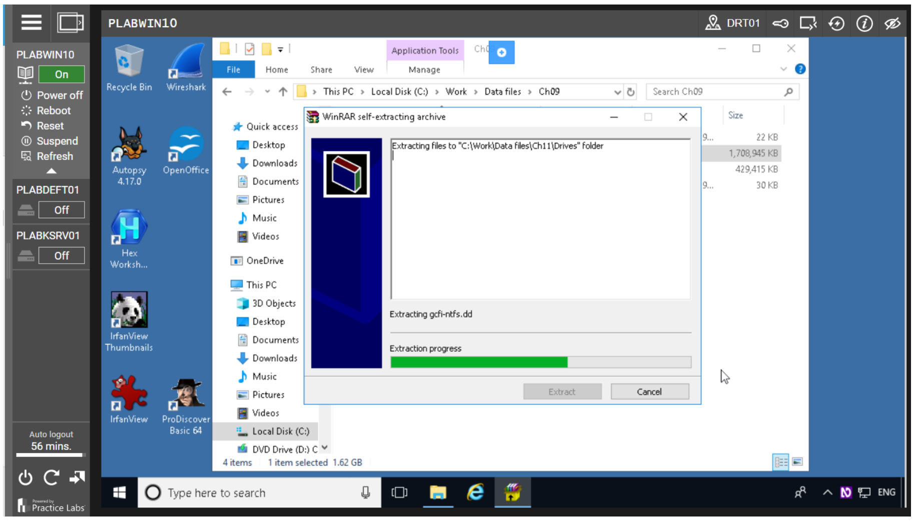

Figure 2. A virtual machine workstation within MindTap running Windows Operating System.

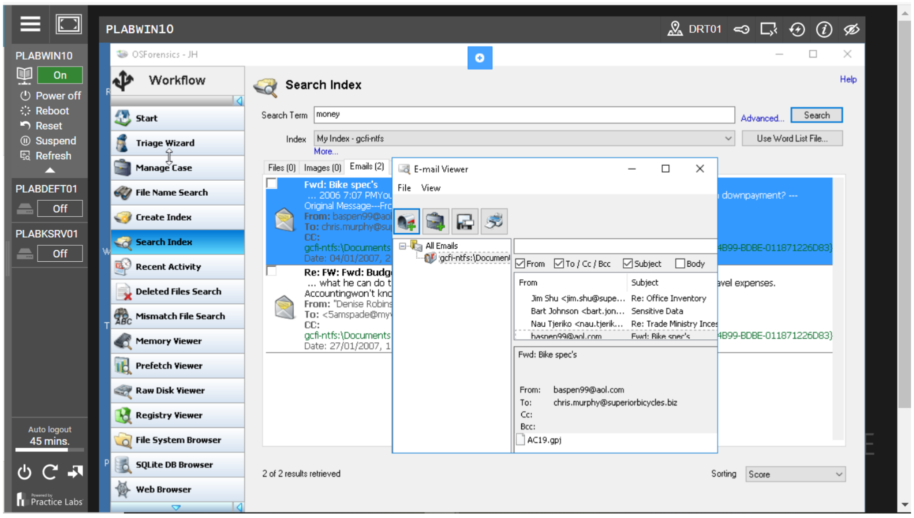

Figure 3. MindTap VM PLABWIN10 with a specific forensic tool being used.

The customized VLab Environment also provides micro-level, per student task completion details to the teaching team. MindTap's personalizing feature is an essential factor that has helped us to achieve a high-level of student engagement and thereby, enhanced learning outcomes. This was echoed in the literature as stated before, e.g., in [15]. For example, similar with Cybulski et al. [33], we have found students had opportunities for social interaction to discuss their learning, experiences and the knowledge by using MindTap VLab community forum. The per-student personalised activity features helped us to provide targeted guidance to our students to boost their completion of weekly tasks. The high levels of student engagement has lead to high success rates in these units, while providing students industry level practical skills. A past student recalled the value of the VLab Environment stating that the use of MindTap with its access to the feature-rich tools was invaluable to get the ins and outs of the practical side of the unit which the industry demands.

We have guided our students of all enrollment modes in their forensic investigation tasks through the unrestricted learning environment of the VLab Environment, resulting in an improved student engagement with tasks and satisfaction for all modes of study. The customization feature of the VLab environment was particularly useful to us, as we were able to select weekly topic summary, hands-on exercises, and quizzes that are aligned with our syllabus. Students can access additional learning resources such as the latest industry news automatically via the VLab environment. To support student learning further, we tailored the VLab environment to provide a progressive, online test aligned with the weekly contents. MindTap's readily available quizzes and other learning materials such as topic summary meant that we could customize these activities and focus on guiding students at their personal activity and performance levels, than investing in developing these features ourselves. Our teaching team also enjoyed the features of MindTap including networking, different operating systems, and the needed forensic tools.

We have utilized live analytic of students' engagement and performance of practical tasks collected by VLab environment as presented in Table 1 (data source: [30]). It allowed us to use student-specific, micro level information, e.g., activities accessed (with links to those), time spent and number of logins to the VLab environment to engage in discussions and support/guide students in completing their pending tasks hence improved learning outcome. According to [23], content knowledge will be vague if the teachers do not support the students to use it purposefully in real life experiences. To get better learning outcome, it is important to have psychological/symbolic tools along with traditional way of teaching theoretical content knowledge. To acquire the learning outcome, the teaching tool needs to be use purposefully. For example, if students gather theoretical knowledge of how to use a forensic tool through curriculum-based content in the course but do not have any knowledge how to do it practically in a digital forensic investigation, they will fail to achieve the learning outcomes. For this reason, acquisition of psychological/symbolic tools requires teachers to take facilitator role and deliberately and intentionally use this tool for students' learning purpose. We have found in our case study that teachers were able to provide hand-on activities, quizzes, topic summary and latest industry news using MindTap VLab environment. Our finding also aligned with connectivism theory that knowledge is actuated by learners' participation in a learning community and to connect with others to collaborate and share, they need appropriate tool to create and construct knowledge [34]. We have found MindTap VLab is excellent teaching tool to engage students to complete hand-on activities virtually in a flexible environment considering time, place, and pace.

MindTap VLab has allowed us to access details on each student's status of tasks by clicking on the engagement levels displayed on the VLab environment, to learn about which tasks they are falling behind. Equipped with weekly status of individual students these information have enabled us to offer targeted supports and guide students in completing the tasks while continuing to monitor their personal progress. This has motivated students to enhance their unit task completions, contributing to higher, sustained success rates of the units since the MindTap VLab adoption as illustrated in Figure 4.

Table 1. Live analytic of students' engagement with weekly activities.

Engagement Level	Number of Logins	Time Spend	Activities
Low	10	0.33	2%
Low	20	4.52	3%
Medium	28	10.26	11%
Medium	42	3.36	9%
High	121	20.49	15%
High	138	51.53	20%

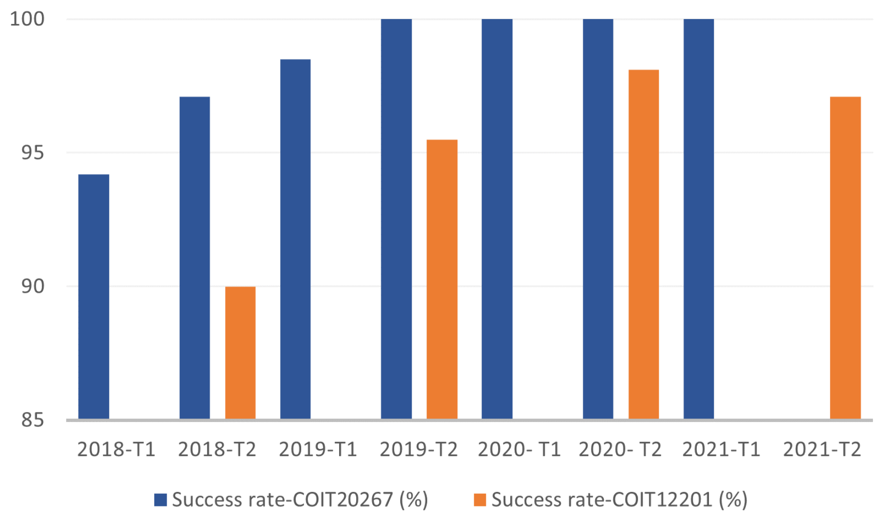

Figure 4. Improved success rates (%) of Digital Forensics units (Empty bars represent the unit not being offered in that Term. T1 refers to Term-1, T2 refers to Term-2).

The use of MindTap VLab has positively impacted the success rates of the units (Figure 4). The unit COIT20267 has maintained a perfect success rate since the last few offerings, with all enrolled students passing the unit. The other unit, COIT12201, has achieved significant improvements in the success rates since the adoption of MindTap. Our observation, therefore, is that students who actually studied the unit (i.e., did not drop out) have all passed the unit since the integration of MindTap (students who withdrew from the unit after the Census date were considered failing the unit which reduced the success rate).

The impact is also reflected in the increased unit satisfaction scores. For COIT12201, the satisfaction score increased from 3.5 in 2019 to 4.5 in 2020, and for COIT20267 it increased from 4.3 in 2019 to 4.7 in 2020 (score out of 5). Student feedback received through the university's unit evaluation surveys echo the quality of the units being outstanding as they got to do activities using many different programs (software tools) in MindTap and then they were able to apply their knowledge to perform forensics investigation of a case study in their assessment task.

In our use of MindTap VLab, it was intentionally setup as a teaching tool together with learning materials by the teacher-mediator in COIT12201 and COIT20267 that gave students the scope to complete the unit successfully, enhancing the success rates of the units (see Figure 4). MindTap was a core part of weekly tutorial activities that the students engaged with, as the teaching staff (teacher-mediator) guided them through the activities. This ensured that students actually used MindTap to engage with their learning, as opposed to providing MindTap as an additional resource for self-learning, which may or may not be used by students on their own. We designed assessments that required students to apply skills developed through the MindTap activities and found that teacher-mediator (subjective sense) had a huge contribution on intentionally using MindTap as a teaching tool (objective sense) [23] in the MindTap VLab environment for developing cognitive and problem-solving abilities in students.

3.2. Custom-Built, Cloud Hosted VLab

It is challenging to design content to teach emerging technologies like Internet of Things (IoT), cloud computing and Quantum computing due to complex and/or expensive laboratory setup required to deliver hands-on exercises. The matter gets further complex when the content aims to deliver complementary emerging technologies like cloud computing, IoT and bigdata together. In 2016, CQUniversity aimed to deliver two complementary emerging technologies under the unit called "Cloud Computing and Internet of Things for Smarter Applications" to prepare students with skills the industry demanded. The content development of the unit faced two main challenges: (1) finding appropriate content in the form of a textbook that covered complementary aspects of these technologies, and (2) complexity of setting up physical lab equipment to cater for students of multi modes enrolments like online and face-to-face, in multiple campuses. The dedicated physical laboratory could be the easiest solution for the second issue, however, it is infeasible and costly for CQUniversity's teaching delivery, since a dedicated lab would have made it difficult to deliver hands-on activities and realistic assessments for distributed campuses and online students. We note that for a single location unit delivery, a dedicated lab would work fine.

This case study will elaborate our journey to address the second challenge which we have overcome through the utilization of industry partnerships and creative use of technology, to design a virtual lab environment using a hybrid approach. Our hybrid approach is a combination of physical and virtual setups that are enabling students to do all hands-on lab activities to cover practical contents of the technologies taught, without a physical lab set up for each campus.

The journey started by CQUniversity joining IBM's Academic initiative which allowed our students to access IBM cloud for free during their study period of this unit. As illustrated in Figure 5, the IBM Cloud Platform as a Service (PaaS) layer allowed us to setup a Virtual laboratory in the cloud so students can access the system ubiquitously. This VLab has three main components: IBM cloud PaaS, external systems, and students. The IBM cloud PaaS has various development environment like NodeRED and Watson IoT system to connect with external systems like sensors, IoT gateway and social media platforms. The external systems allow students to access physical systems remotely via cloud as illustrated in Figure 5. The external systems connected via middleware tool NodeRED allow students to access hardware signal, their interface and data for development purposes. The student terminal in Figure 5 can be any computing device installed with local NodeRED to connect with external system and IBM Cloud using node based connection via NodeRED. To ensure faster development and deployment via terminal, the student's computing device can use IBM cloud foundry and/or IBM Cloud CLI (Command Line Interface).

The VLab allows students to develop and use cloud-based IoT applications without the need for real IoT hardware. Using the VLab, students can build a virtual sensor network across a city, write an application that monitors the sensor data, and then use the data to solve business problems. Students are able to access their laboratory device and tools from any geographical location and independent of specific software or hardware. This has given the teaching team an opportunity to design Problem Based Learning (PBL) assessments that can be solved by students using industry scale technologies.

The VLab allows CQU to offer the same lab facilities for face to face and online students. In the VLab, without performing any physical or logical installation, students can build sensor networks and smart applications based on sensor data to address a complex business problem. For example, students can deploy a virtual sensor network across a real city using OpenStreet map in the VLab; then write the software to monitor the position of delivery trucks using flow-based development tool called NodeRED for visual programming; then collect system's data for analysis to determine how the business can lower delivery costs. The flexibility of using both open source and cloud based tool to design Internet of Things (IoT) systems have improved students exploring and learning opportunity compare to physical laboratory. The VLab has reduced installation time and cost along with hardware procurement requirements. This has enabled teachers (mediator) to design industry level learning exercises and assessments which are otherwise not feasible. The industry collaboration on this VLab has allowed students to share their work using IBM's readily available cloud server and domain to make it accessible from anywhere in the world and ready for business operation. The readily shareable facilities in the VLab has motivated them to push their learning boundaries and to grow their learning network that have resulted improved learning outcome and success rate.

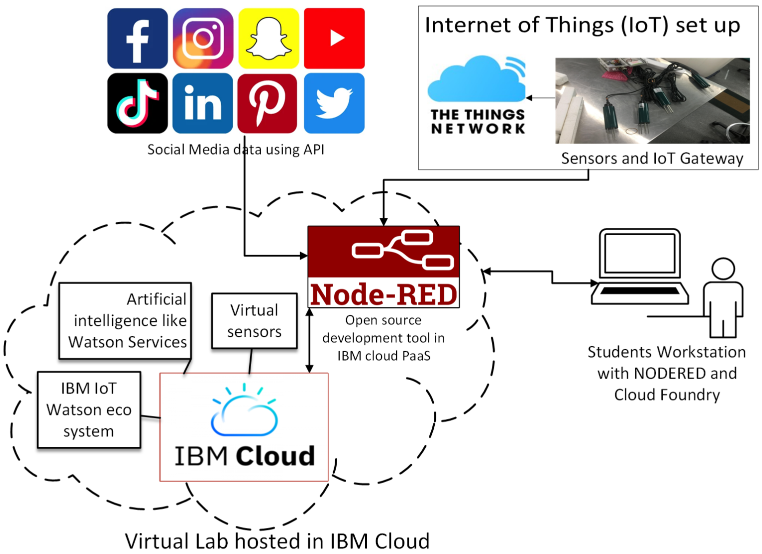

Figure 5. The architecture of the custom-built VLab.

During COVID-19 pandemic, our custom-built VLabs became a blessing for students for using hybrid approach, with a combination of physical and virtual setup. The VLab has allowed us to design authentic assessments where students focus on using technology to solve real business problems. Students are to solve the business problems using the knowledge learned and the available cloud tools in the virtual lab. This makes the virtual lab a core part of their learning activities. Students were challenged in these PBL assessments and, with the guidance and help of the teaching team, these challenges motivated students to actually engage with the activities using the virtual setup to be a lifelong learner as they were bound to think out of the box. As stated in learning theories, the teaching tools have rich educational potential, but these remain inactive if there is no human mediator (teacher as a subjective sense) to facilitate the learning process for learners. The facilitation of learning process by the human mediator can come from both guiding students through the virtual lab activities, as well as designing assessments that require skills developed through the virtual lab activities. This resonates with the way we have used the virtual labs, and therefore, our conjecture is that the VLabs will be an ordinary tool, if teachers do not facilitate learning through guidance and designing PBL exercises and assessments for students to solve using skills obtained from VLab activities, to master reasoning and problem solving skills [23].

Furthermore, the virtual lab caters to all levels of students and allows them to continue their learning beyond the unit content. For example, a more curious student will be able to expand on the unit learning of 'language translation tool' and connect it to 'IBM Watson', which is Artificial Intelligent (AI) service, to create an intelligent language translation tool to solve a business problem. In a virtual lab, students are allowed to expand their knowledge and experience in all categories of cloud services and tools like security, networking, web application, AI and storage, offered by IBM Cloud.

Overall, the custom-built VLab has improved students satisfaction as reflected in students unit evaluations comments and feedback. In Figure 6, the average student satisfaction score of the units, "COIT20260-Cloud Computing and Internet of Things for Smarter Applications" and "COIS13034-Cloud Based Smart Applications Management", are plotted where *X*-axis represents year and *Y*-axis represent success rate in 5-Point Likert Scale with 5 being the best. As illustrated in Figure 6, the student satisfaction score gradually increased from 4 to 4.9 (in average) out of total 5. The student satisfaction score is calculated based on quality teaching, assessments and learning resources. Both of the units have used custom-built VLab in the unit since 2017. As their were no changes in the unit except introduction of VLab in 2017, we can safely conclude that the VLab has contribution to improve students satisfaction which is also evident in students feedback for the units. Although there were adjustment and struggling periods for first two offerings, in 2017, as detailed in Section 4. These challenges were due to adaptation and evolving changes of technologies around the VLab, however, the advantages overpowered all the challenges.

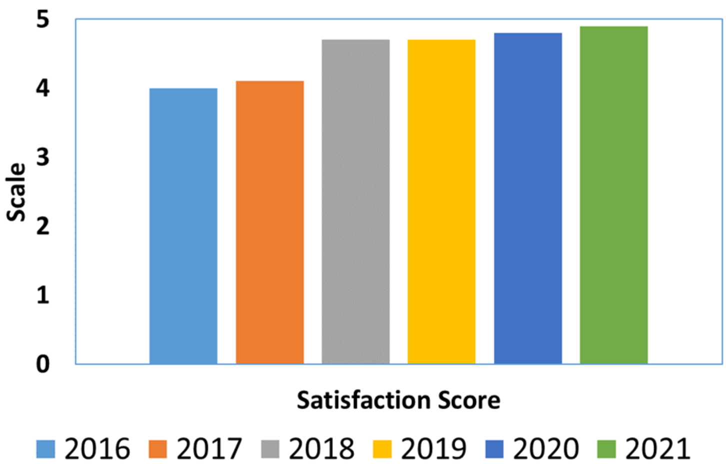

Figure 6. Student satisfaction scores in Cloud Computing units since the adoption of the custom-built VLab.

4. Discussion and Limitations

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) assessments for students that will be solved (subjective sense) using industry scale emerging technologies. Based on constructivism theoretical perspectives, George Siemens [16] stated that connectivism views that learners should develop a learning network and make connections between ideas embedded throughout that network. In the context of ICT tertiary education, VLabs are connected online platforms for ICT students to solving the real business problems. By getting help and guidance from the teaching team, the paper has found that student satisfaction score is higher in the units that implemented VLab compared to their previous offerings without VLab. The adoption of MindTap and custom-built VLabs have provided the students equitable access to an industry-relevant learning environment to prepare work-ready graduates skilled in emerging technologies. This has also allowed us to support students with targeted guidance, and enhanced student engagement and completion of the practical tasks, leading to higher success rates. This study has revealed that using virtual labs to replace or complement the physical lab facilities supports the ubiquitous learning from any place, time and pace in a flexible environment.

VLab is a technological tool [24] which gives facility to students to contribute in Problem Based Learning (PBL) and synthesize ideas, developing learning network and solving any real business problem using theoretical knowledge by making connections between ideas embedded throughout the network [25]. In Vygotsky's time the psychological/symbolic tools were identified as language, sign, letters, mathematical codes etc., however, we have found in our current study that in the 21st century, technological tools can be addressed as teaching tool where it meditated as object to organize individual cognitive and learning functions in different contexts.

Our observations from these case studies have indicated that even though the custom-built and commercial VLabs are allowing students to solve real business problems using cloud hosted tools to fulfill assessment criteria, they need human facilitators to give guidance and help to overcome mentioned challenges. Therefore, our conjecture is that custom-built and commercial VLabs both can be teaching tools to use for solving any practical business problems by students, but without human mediation (teachers' support) the VLabs will be identified as another content item (teaching material), rather than a tool as a learning material. We observed that using VLabs with support from the teaching team, students had the opportunity to solve real business problems. This provided them a sense of satisfaction with their learning journey which students expressed through their feedback comments in the end of term unit evaluation surveys run by the university. This experience may have significantly contributed to the enhanced satisfaction scores of the units. Figure 7 illustrates that our result shows teachers' support (human mediator) and VLabs (teaching tool) are interlinked together in a dialectical way which is important to consider to achieve successful learning outcomes.

Despite the overall success, the VLab has raised unique challenges in its initial offerings due to some students' traditional expectation to perform lab exercises using physical lab setups. This was successfully overcome using support of the entire teaching team (human mediator), training documents and video instructions (teaching tool) for students. Furthermore, the evolving nature of emerging technologies like IBM Cloud and IoT technologies also added an extra layer of complexity which was addressed by continuous testing of entire virtual lab setup throughout the teaching term.

It is important to note that the VLabs' availability is highly dependent on the steady internet connection. While this generally is not an issue in Australia, occasionally some students face internet connection issues which can cause dissatisfaction among them. However, students are able to continue their work and complete it at a later time when they get their internet connection back. So, with a bit of patience to persevere during the occasional internet connection breakages, VLabs can offer a lot of benefit to the institutes and their learners.

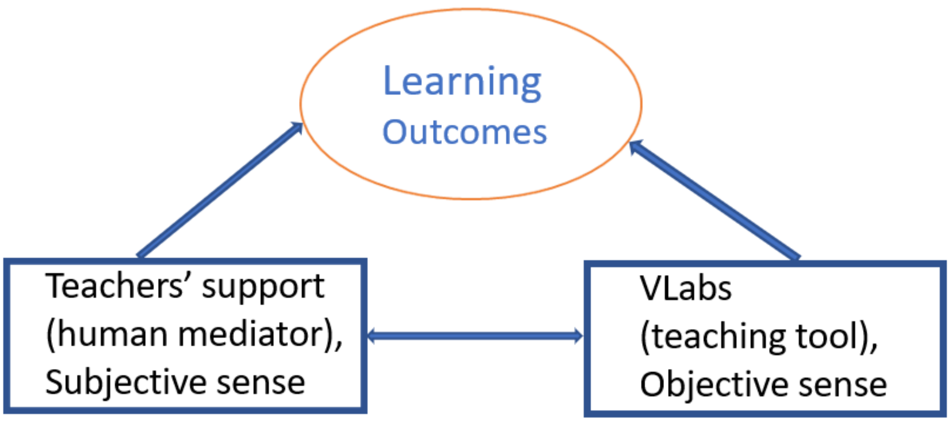

Figure 7. Dialectical relationship of teachers' support and VLabs for achieving unit learning outcomes.

In this case study, we have reflected on our experience from teaching specific ICT tertiary subjects using the mentioned approaches to VLabs, hardware setups, and software tools, over a number of years. The learning theories that we have discussed in this paper aligned with our practice of how we used the VLabs in our teaching, which may not be seen as a generalization for VLab usage. We also note that our findings are not based on a research study, rather from a case study, however, our observation is on-going and the practice is supporting our students' learning experience positively. Nevertheless, our experience and conjectures will be helpful to educators when deciding on the adoption of VLabs in their teaching.

5. Conclusions

In this paper, we have reviewed the use of Virtual Laboratories (VLabs) and their utility in the tertiary education sector through the lens of learning theories, to understand their features and benefits, and most importantly, how VLabs should be used. Accessing online lab facilities to undertake hands-on activities from anywhere and anytime is imperative not only during COVID-19 lockdown periods, but in general at anytime as most of the universities are offering online mode teaching. VLabs, accessed via an internet connection, can offer learners the crucial infrastructure required to complete their lab tasks without attending physical lab facilities which is particularly helpful to distance education students. On-campus students can also re-emphasize their learning using the on-line labs outside their class times. Despite their benefits, choosing the right type of VLab is not a simple task since it must be accompanied by an effective and improved learning process. The presented case studies and analyses have revealed that teachers' support (human mediator) and VLabs (teaching tool) are interlinked together in a dialectical way which is important to consider to achieve successful learning outcomes.

Author Contributions: Conceptualization, J.H. and B.R.; methodology, J.H. and A.D.; validation, A.D.; formal analysis, J.H., A.D.; investigation, J.H. and B.R.; resources, J.H.; writing—original draft preparation, J.H., A.D. and B.R.; writing —review and editing, J.H., A.D. and B.R.; visualization, J.H., A.D.; project administration, J.H.; funding acquisition, J.H. and B.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by CQUniversity Learning and Teaching Awards LR6321, LR6356.

Conflicts of Interest: The authors declare no conflict of interest.

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