Design of a Technology-Enhanced Pedagogical Framework for a Systems and Networking Administration course incorporating a Virtual Laboratory

Rukshan Athauda[1], Tareq Alkhaldi[2], Ilung Pranata[3], Daniel Conway[4], Charles Frank[5], William Thorne[6], Ryan Dean[7]
School of Electrical Engineering and Computing
The University of Newcastle
Australia
[1]Rukshan.Athauda@newcastle.edu.au, [2]Tareq.Alkhaldi@newcastle.edu.au, [3]Ilung.Pranata@newcastle.edu.au,
[4]Daniel.Conway@newcastle.edu.au, [5]Charles.Frank@uon.edu.au, [6]William.Thorne@uon.edu.au, [7]Ryan.Dean@uon.edu.au

***Abstract*— Practical hands on lab activities are crucial to learning in fields such as computing, engineering and science. Advances in technologies have allowed the design and development of virtual and remote laboratories with many benefits overcoming constraints of physical laboratories. In literature, we observe a number of virtual labs implemented for systems-level courses in computing, using virtualization and cloud computing technologies. Although benefits of such technology-enhanced labs are well-known, the best approach to integrate these labs to achieve best outcomes for learning is still an exploratory area of research. In this paper, existing literature on virtual labs implementation for systems-level courses in computing is analyzed and classified into two stages of evolution. In the first stage, technical design & evaluation is the focus while in the second stage, pedagogy and learning theories and principles are used as the basis in designing technology innovations as well as teaching & learning activities. The second stage has the advantage of theoretical principles guiding the design of teaching and learning activities and technology artifacts with a focus to achieve learning outcomes and thus a higher potential to achieve learning goals. However, we observe only a few studies taking this approach. This paper presents the design of a holistic technology-enhanced pedagogical framework incorporating a virtual laboratory for a systems and network administration course. The framework applies theories such as Constructive Alignment for curriculum design and Kolb's Experiential Learning Cycle, Bloom's Taxonomy and Collaborative Learning to design teaching & learning activities and assessments. Technology artifacts such as virtual labs, a feedback tool, student and teacher dashboards, on-line quizzes and discussion boards are incorporated. Our future work will evaluate the framework in real class environments.**

Keywords— Virtual Labs, Systems-level courses, Technology-enhanced Pedagogical Framework, Learning Theories

I. INTRODUCTION

In many fields of study, such as computing, sciences and engineering, hands on activities are paramount to learning. In higher education, it is common for students to conduct experiments in laboratory settings as a part of teaching and learning activities. Advances in technology has resulted in technology enhanced laboratory environments providing many benefits. These labs are broadly classified as remote and virtual labs [1]. In remote labs, students access physical lab equipment remotely and conduct experiments. In virtual labs, learners conduct experiments in computer simulated environments (also termed simulated labs).

In literature, a number of advantages of using virtual and remote labs are outlined [2]. Improved 24x7 access to learners both on-campus and distance to conduct experiments. Learners having the flexibility and freedom to re-set, repeat and re-trial experiments and explore at their own convenience with minimal restrictions in a safe environment. In addition, virtual environments provide newer opportunities for learning such as simulations focused on pedagogical principles and scaffolding learners which is not practical in physical lab settings. Thus, with all its advantages and continuing advances in technology, it is imperative that we foresee further application of technology-enhanced labs in future learning contexts.

In system-level courses in computing education, such as information security, networking, system administration and operating systems, hands-on activities require students to configure hardware and system-level software (operating systems, firewalls, security settings) with administrative privileges in complex networked environments. Such laboratory activities require specialized physical labs with equipment isolated from other campus networks. This can be prohibitive, both financially and practically. In addition, such specialized labs inherit the constraints of physical labs such as restricted access limited to lab opening hours.

Virtualization and cloud computing technologies have provided the means to implement virtual computing labs that enable students to create, configure and deploy virtual IT infrastructure (e.g. virtual machines, switches, routers, etc.) and conduct experiments, without the need to have specialized physical labs for system-level courses in computing.

In literature, we observe different types of implementations of virtual labs for system-level courses in computing using virtualization technologies. Many of these implementations focus mainly on technical designs providing improved access for teaching and learning. Although technology-enhanced labs provide significant benefits, how to design such labs for best outcomes for learning is still an open research question. In [2] authors argue that the combination of a good pedagogical framework, learner support, content and tutor interaction, are all essential components that create a learning environment where students can excel and achieve higher learning outcomes. Using pedagogy and learning theories and principles (PLTs) as a basis for designing technology interventions in educational contexts has the potential to achieve higher

978-1-5386-1174-6/18/$31.00 ©2018 IEEE

learning outcomes. In this paper, the use of PLTs as a basis for developing technology interventions incorporating a virtual lab for a systems and network course is presented.

The paper is organized as follows: Section II discusses related studies that develop virtual labs for system-level courses in computing. Section III presents the proposed framework. Firstly, the application of PLTs are presented. Next, the technology artifacts of the proposed framework are discussed. Finally, section IV concludes the paper.

II. RELATED WORK

Implementations of virtual labs for system-level courses in computing can be classified into two stages of evolution: (i.) *Level I: Technology innovation and evaluation stage,* and (ii.) *Level II: Technology, Pedagogy and Evaluation*.

Most studies in literature can be categorized at Level 1. At Level 1, the focus of the study is the technical design and evaluation. Capabilities of technology innovations to overcome existing limitations and new opportunities for learning are discussed and demonstrated. The details of the technical design are presented. Evaluation is conducted using a case study where the technology intervention is implemented in real class environments. Level I studies can be further categorized based on the level of evaluation as follows: *Technical Design (TD) only*; *Technical Design and Technical Evaluation (TD&TE); and Technical Design, Technical Evaluation and Learning Impact (TD, TE & LI)*

In TD stage, studies focus on technical design of technology innovations and no evaluation is presented. In the context of virtual labs in system-level courses in computing, many studies in TD level focus on the details technical designs of implementing virtual labs. For instance, in [3], the authors present an environment using full and operating-system virtualization that can be used in networking, systems administration and cyber security education. Other studies that fall into this category include [4], [5], [6], [7] and [8].

In TD & TE stage, studies not only discuss the technical design but also present an evaluation of the technology intervention focused on technology acceptance and user experience. For instance, in the study presented in [9], the authors use a public cloud environment (i.e. Amazon EC2) to implement cybersecurity labs. The advantages and detail technical configurations of implementing a cybersecurity lab are discussed. The authors teach a cybersecurity course using the cloud lab and evaluate the acceptance of such labs using student surveys. Other studies that fall in this category include [10], [11], [12], [13], [14], [15] and [16].

Some studies in Level I also focus on evaluating the impact on learning due to the technology intervention which is classified as TD, TE & LI. Often an experiment is conducted with a pre/post-test of student learning evaluation (i.e. assessments score and survey results) or control and experimental groups of students with the technology innovations. For instance, in [17], a virtual network lab is created along with two tools – Designer and Builder which allows students to design a network scenario and deploy the scenario in a virtual environment. The tool is evaluated using a pre- and post-test to consider the impact of learning. Also, student perspectives are evaluated using survey questions. Other studies that fall in this category include [18], [19], [20] and [21].

We found only a few studies in literature at Level II. At Level II, studies explicitly use PLTs to design teaching and learning activities and technology innovations. The studies evaluate both technology acceptance, user experience and impact of learning. For example, in [22], Kolb's Experiential Learning Cycle (ELC) [23] is used to re-design hands-on lab activities incorporating a virtual computer lab in an information security course. A control and experimental group of students were evaluated for their learning experience and outcomes. The control group conducted the lab activities individually following a "cook-book" approach to hands-on activities, while the experimental group's learning activities were designed to follow each phase of Kolb's ELC. The teaching & learning activities (TLAs) were evaluated on learning impact and outcomes based on student surveys and quiz results. Other studies in this category include [24], [25] and [26].

The advantage of using PLTs to design technology innovations and TLAs in Level II is that the educator has formal principles and theories to guide the design of TLAs and technology innovations. This approach has a higher potential for success compared to ad-hoc technology interventions. We observe that in the context of virtual labs for system level courses in literature, there are many (19) studies at Level I while only few (4) studies at Level II. There is potential to further investigate applying PLTs in designing technology interventions (such as virtual labs in system level courses). In the next section, a design of a technology intervention at Level II based on a number of PLTs for a systems course in computing incorporating a virtual lab is presented.

III. PROPOSED FRAMEWROK

As a first step, context of the learning environment where the intended technology intervention will be applied is identified. In this study, an introductory systems and network administration course in the undergraduate computing program is considered. The course is delivered in a 12-week semester with 2 hours of lecture and 2 hours of lab contact per week within a term.

A number of PLTs are applied in designing the technology intervention as shown in the subsequent sections.

A. *Curriculum Design*

Constructive Alignment [27] (CA) provides an overarching framework for curriculum design and practice. In Constructive Alignment, the intended learning outcomes (ILOs), teaching and learning activities (TLAs) and assessment tasks (ATs) are aligned.

In designing the curriculum for the course, CA is applied. The ILOs are outlined. Next, the TLAs and ATs are designed to align to ILOs. Table 1 depicts ILOs alignment to TLAs and ATs.

As the focus of the technology intervention is on labs (i.e. virtual labs), the focus of the design of TLAs was hands-on lab activities. A number of PLTs were considered as discussed below.

B. *Design of TLAs*

In Kolb's Experiential Learning Cycle (ELC) [23], learning takes place in four stages. Concrete Experience:

Table 1. Alignment of Learning Outcomes, Teaching & Learning Activities and Assessment Tasks

Intended Learning Outcome (ILO)	Teaching and Learning Activities (TLAs)	Assessment Tasks (ATs)
ILO 1: Understand the fundamentals principles of networks and network communication (hardware, models, protocols and security).	L1 – L5, L9 – L11, review exercises T1-T5 & T9-T11	A1, PT1, PT2, Formal Exam
ILO 2: Understand the role of PC-based and Network Operating Systems in organizations	L1– L2, L6 – L8, T1–T3, T6 – T9	PT1, PT2, A2
ILO 3: Demonstrate the ability to design networks and Active Directory solutions for organization scenarios	L1-L8, L11	A1, A2, Formal exam
ILO 4: Demonstrate ability to install, configure and troubleshoot PC, NOS and network services	Practical activities in T1 – T3, T6-T9	PT1, PT2

*Lx – Lecture x; Tx – Tutorial/Lab x; Ax – Assignment x; PTx – Practical Test x

means direct experience by performing a task. Reflective observation: means observation and reflection on the experience. Abstract conceptualization: means formation of new concepts and learning from the experience. Active experimentation: means applying what is learnt. Kolb argues that for a complete learning experience, a learner must engage in all four stages of the cycle.

In designing, hands-on activities, Kolb's ELC is applied. The lab activities are designed to cover all stages of ELC. In addition, revised Bloom's taxonomy [28] was referenced in designing lab activities to encourage higher levels of learning. Group based activities are incorporated enabling Collaborative Learning [29]. In literature, it has been shown that collaborative work in labs improve competency, confidence and interest in students ([22], [24]). Thus, each lab was designed applying these principles.

The labs were designed by modularizing labs activities to tasks. Each task applies different stage(s) of Kolb's ELC. After a topic is covered, review exercises (based on different Bloom's levels), group-based activities (enabling Collaborative Learning) and exploratory exercises are integrated to avoid monotonous "cook book" style approach in lab exercises.

Figure 1 depicts the schematic flow of Lab 1's activities as an example of incorporating Kolb's ELC and Bloom levels. In Lab 1, Task 1 provides explanation and step-by-step instruction to create a virtual machine using a selected hypervisor. In Task 2, explanation and instruction to install a guest OS on the configured VM is provided. In Tasks 1 and 2, learners learn through direct experience which maps to the Concrete Experience (CE) stage of Kolb's ELC. In Task 3, a set of review questions are provided. The review questions span from Bloom Level 1 (BL1) Remembering (For example, "what is a hypervisor?") to Bloom Level 4 (BL4) – Analyzing level questions (e.g. "Describe a situation where using a VM is not appropriate"). This activity also maps to Reflective Observation (RO) and Abstract Conceptualization (AC) stages in ELC. The student in the lab class is requested to partner with another member in class to discuss and answer the review questions. Next, the group will post their answers on the Learning Management System's (LMS) Discussion Board and share with the class. Also, the group reviews other group's answers and comments on them. This peer-review process leads learners to an activity at Bloom

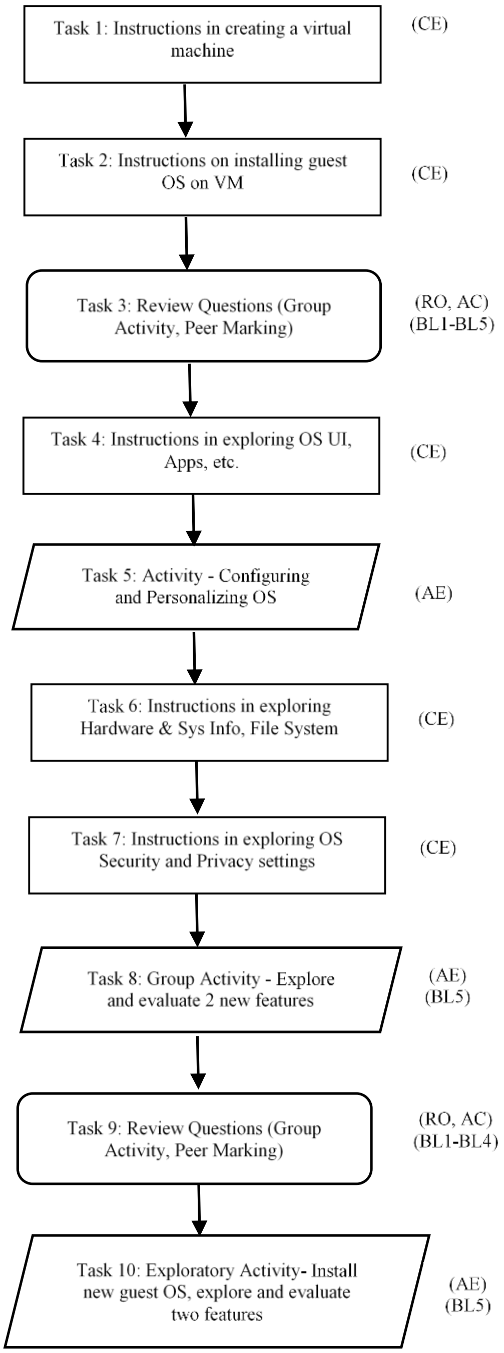

Fig. 1. Lab 1's activities designed based on Kolb's ELC and Bloom Levels

Level 5 – Evaluating stage. Task 4 provides explanations and step-by-step instructions to navigate and explore applications and guest OS's user interface which maps to CE stage of ELC. In Task 5, learners are asked to customize the OS settings and configurations to personalize to their preferences. The learners explore and configure OS features which maps to the Active Experimentation (AE) stage of Kolb's ELC. Tasks 5 & 6 explores and explains OS's hardware and device configurations, file system, security and privacy settings mapping to CE stages of ELC. In Task 8, students explore new features of the OS. Also, students partner with another class member and discuss each other's features. The group posts two features on LMS's Discussion Board to share with the class. Also, the group evaluates and comments on at least one other group's posts mapping to AE stage of ELC and Bloom's Level 5 – Evaluating stage. Task 9's review questions consists of review exercises from the content covered in the lecture. This activity maps to RO and AC stages in ELC. Task 10 is an exploratory activity demonstrating their understanding and skill of the entire lab. Learners create a VM and install a guest OS (different OS from task 2), explore features and post discussion on features and evaluate other groups' features. This activity is completed by learners without explicit step-by-step instructions demonstrating their level of learning in the lab. This activity maps to AE stage of ELC and Bloom's Level 5.

C. *Design of ATs*

Applying CA, the assessment tasks are aligned to ILOs. The ILOs - ILO1 & ILO2 develop the fundamental knowledge and understanding of concepts whereby ILOs - ILO3 and ILO4 aim to demonstrate applying this knowledge and skills to solve real-world scenarios/problems. ILO1 and ILO2 are required fundamental knowledge for A1, A2, PT1 and PT2. In A1 and A2, students design networks and Active Directory solutions to real-world scenarios directly aligning to ILO3. PT1 and PT2 assesses competency in hands-on configuration tasks to real-world scenarios directly aligning to ILO4. Formal exam covers assessing of ILO1-ILO3.

In addition to summative assessments, formative assessments are applied. In literature, formative assessments are considered an essential component of assessment work and its development can raise standards of achievement [30]. A number of TLAs and tools such as review questions, discussion boards and online quizzes provide formative feedback. Both self- and peer-assessment is incorporated with tutor and peer interaction. In addition, to provide formative feedback for hands-on lab activities, an innovative automatic Feedback Tool is implemented (discussed in the next section). The next section presents the technology architecture and artifacts of the proposed framework.

D. *Technology Architecture and Artifacts*

The technology architecture of the proposed framework is shown in Figure 2. The technology artifacts consist of the Virtual Laboratory and the Student Interface, Feedback Tool, Student and Teacher dashboards and LMS.

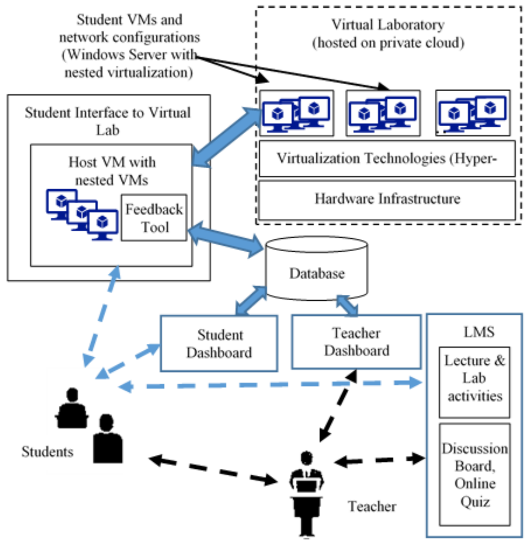

Fig. 2. Architectural design of technology artifacts of the proposed framework

Learning Management System (LMS): The Learning Management System (LMS) provides an online portal for learners in the course. Blackboard [31] is the adopted LMS at the university and is used as the online course portal. LMS hosts all content including lectures presentations, lecture recordings, laboratory sheets, assessments, discussion boards, progressive marks, announcements and links to student lab portal and dashboards. All lectures delivered are video captured and hosted on the LMS.

Virtual Laboratory and Student Interface: The virtual laboratory is hosted on a private cloud on campus. Microsoft's Hyper-V is used as the virtualization platform. A private cloud hosts virtual machines (VM) for each student. The host VM of each student has Windows Server 2016 with nested virtualization enabled. The host VM provides each student with a sandboxed environment to create and configure guest VMs and networks to conducts different laboratory activities without impacting campus networks. Quest's vWorkspace is utilized to manage the private cloud environment and also provide access to the host VM via the browser or a client application – Student Interface to Virtual Lab. Figure 3 below depicts access to host VM.

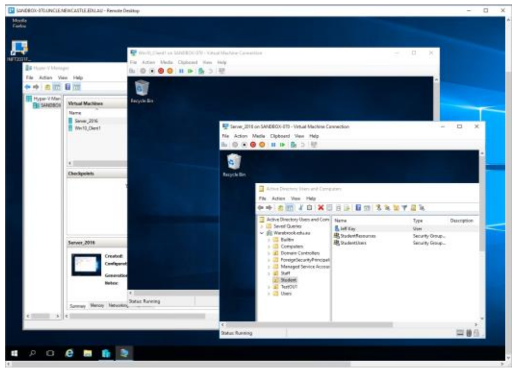

Fig. 3. Access to virtual lab via Student Interface

Feedback Tool and Dashboards: It is impractical for the tutors to manually check each student's configurations and provide feedback. Thus, a Feedback Tool is developed that verifies each student's lab configuration and generate a report. Students run the Feedback Tool and selects a particular lab to verify. The Feedback Tool uses Powershell [32] scripts which checks the student's lab configurations and generates a lab report specifying correct and incorrect configurations for the lab. The tool is designed to update configurations through XML configuration files. The Powershell scripts and configurations files are stored on a file server and managed centrally. A sample output of a report is show in Figure 4. A green tick represents a correct configuration while a red cross represents an incorrect configuration. In the feedback report, an option is provided for students to submit their formative feedback reports to a centralized database. The database is accessed from the student and teacher dashboards. The student's provides a view for the student's individual progress of the labs providing an overall view of the student's progress. The teacher's dashboard provides a collated view of students' progress. With the help of the dashboard, the tutor can assess students' progress and identify areas where students may be struggling and intervene where necessary.

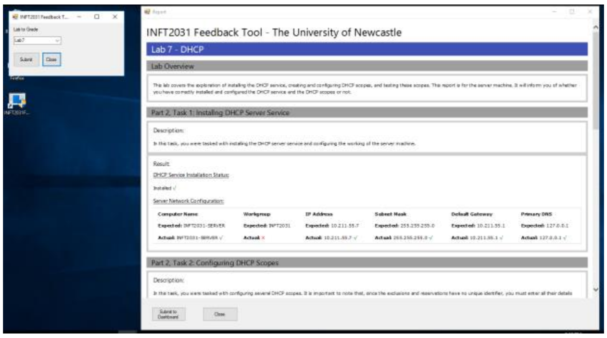

Fig. 4. A sample report from Feedback Tool

IV. CONCLUSION

In this paper, the design of a technology-enhanced pedagogical framework for a systems and networking course incorporating virtual labs is presented. Firstly, related work on virtual labs for systems courses in computing is classified into two stages: Level I which focuses on technical design and evaluation and Level II focuses on using pedagogy and learning theories and principles (PLTs) to design technology interventions in education contexts and evaluate its impact on learning. Level II approach has the advantage of following PLTs in guiding their design of technology interventions with a higher potential for success than ad-hoc technology interventions. We observe only a few studies taking a Level II approach when incorporating virtual labs for systems level courses in computing.

In the proposed framework, a Level II intervention is designed based on a number of PLTs. The curriculum is designed applying Constructive Alignment. The design of teaching and learning activities applied Kolb's ELC, Collaborative Learning, Bloom's Taxonomy and Formative Assessments. Technology artifacts included virtual labs, discussion boards, online quizzes, a Feedback Tool and dashboards for students and teachers. In future, we aim to evaluate the framework in real classroom environments.

REFERENCES

[1] J. Ma, and J. V. Nickerson, "Hands-on, simulated, and remote laboratories: A comparative literature review," ACM Comput. Surv., vol. 38, no. 3, pp. 7, 2006.
[2] T. Alkhaldi, I. Pranata, and R. I. Athauda, "A review of contemporary virtual and remote laboratory implementations: observations and findings," Journal of Comp. in Education, vol. 3, no. 3, pp. 329–351, Jun. 2016.
[3] K. E. Stewart, J. W. Humphries, and T. R. Andel, "Developing a virtualization platform for courses in networking, systems administration and cyber security education," Spring Simulation Multiconference, San Diego, California, 2009.
[4] D. Hu and Y. Wang, "Teaching Computer Security using Xen in a Virtual Environment," Int'l Conf. on Inf. Security and Assurance (ISA), Busan, 2008.
[5] P. Li and L. W. Toderick, "Cloud in cloud: approaches and implementations," ACM Conf. on Information Technology Education, Midland, Michigan, USA, 2010.
[6] A. Soceanu, M, Vasylenko, and A. Gradinaru, "Improving Cybersecurity Skills Using Network Security Virtual Labs," Int'l MultiConference of Engineers and Computer Scientists (IMECS 2017), Hong Kong, 2017.
[7] G. Gercek, N. Saleem, and D. Steel, "Implementing cloud based virtual computer network labs for online education: Experiences from a phased approach," Int'l Journal of Online Engineering (iJOE), vol. 12, no. 3, 00.70-76, 2016.
[8] M. Wannous, H. Nakano, T. Kita, and K. Sugitani, "A core system for a web-based virtual computer laboratory," Int'l Conf. on Information Technology based Higher Education and Training, Kumamoto, Japan, 2007.
[9] K. Salah, M. Hammoud and S. Zeadally, "Teaching Cybersecurity Using the Cloud," IEEE Transactions on Learning Technologies, vol. 8, no. 4, pp. 383-392, 2015.
[10] C. Yan, "Bulid a laboratory cloud for computer network education," Int'l Conf. on Computer Science & Education (ICCSE), Singapore, 2011.
[11] P. Li, L. W. Toderick, and P. J. Lunsford, "Experiencing virtual computing lab in information technology education," ACM Conf. on Information Technology Education (SIGITE), Fairfax, Virginia, USA, 2009.
[12] J. Prieto-Blazquez, J. Arnedo-Moreno and J. Herrera-Joancomarti, "An Integrated Structure for a Virtual Networking Laboratory," IEEE Transactions on Industrial Electronics, vol. 55, no. 6, pp. 2334-2342, 2008.
[13] P. Li and T. Mohammed, "Integration of virtualization technology into network security laboratory," Frontiers in Education (FIE), Saratoga Springs, New York, USA, 2008.
[14] W. Zhu, "Hands-On Network Programming Projects in the Cloud," ACM Technical Symposium on Computer Science Education, Kansas City, Missouri, USA, 2015.
[15] S. Duigna and T. Hall, "Using Platform Virtualisation to Teach System Architectures in Undergraduate Computer Science–An Evaluation of Student Learning Experiences," Innovative Techniques in Instruction Technology, E-learning, E-assessment, and Education. 2008, Springer.
[16] R. I. Dinita, G. Wilson, A. Winckles, M. Cirstea and A. Jones, "A cloud-based virtual computing laboratory for teaching computer networks," Int'l Conf. on Optimization of Electrical and Electronic Equipment (OPTIM), Brasov, 2012.
[17] M. Wannous and H. Nakano, "Constructing and Tuning a Web-based Virtual Computer-Networks," IEEE Multidisciplinary Engineering Education Magazine, vol. 5, no. 2, 2010.
[18] A. Ruiz-Martinez, F. Pereniguez-Garcia, R. Marin-Lopez, P. M. Ruiz-Martinez and A. F. Skarmeta-Gomez, "Teaching Advanced Concepts in Computer Networks: VNUML-UM Virtualization Tool,"IEEE Transactions on Learning Technologies, vol. 6, no. 1, pp. 85-96, 2013.
[19] M. Anisetti and T. Mohammed, "Learning computer networking on open paravirtual laboratories," IEEE Transactions on Education, vol. 50, no. 4, pp. 302-311, 2007.
[20] N. I. Sarkar and K. Petrova, "Design and Evaluation of a Web-Based Tool for Teaching Computer Network Design to Undergraduates," Int. J. Web-Based Learn. Teach. Technol., vol. 6, no. 4, pp. 39-59, 2011.
[21] X L. Xu, D. Huang and W. T. Tsai, "Cloud-Based Virtual Laboratory for Network Security Education," IEEE Transactions on Education, *vol.* 57, no. 3, pp. 145-150, 2014.
[22] A. Konak, T. K. Clark, and M. Nasereddin, "Using Kolb's Experiential Learning Cycle to improve student learning in virtual computer laboratories," Comput. Educ., vol. 72, pp. 11-22, 2014.
[23] Kolb, D.A., Experiental learning: Experience as the Source of Learning and Development. Englewood cliffs, 1984.
[24] Konak, A. and M.R. Bartolacci, "Using a virtual computing laboratory to foster collaborative learning for information security and information technology education," Journal of Cybersecurity Education, Research and Practice. 2016.
[25] W.-Y Hwang, C. Kongcharoen and G. Ghinea, "To enhance collaborative learning and practice network knowledge with a virtualization laboratory and online synchronous discussion," The Int'l Review of Research in Open and Distributed Learning, vol. 15, no. 4, 2014.
[26] C. Kongcharoen, W-Y. Hwang and G. Ghinea, "Synchronized pair configuration in virtualization-based lab for learning computer networks," Journal of Educational Technology & Society, vol. 20, no. 3, pp. 54-68 2017.
[27] J. Biggs, Teaching for quality learning at university: What the student does. 2011: McGraw-Hill Education.
[28] L.W Anderson, et al., A taxonomy for learning, teaching and assessing: A revision of Bloom's taxonomy. New York. Longman, 2001.
[29] M. Laal and S.M. Ghodsi, Benefits of collaborative learning. Procedia-Social and Behavioral Sciences, vol. 31, pp. 486-490, 2012.
[30] P. Black and D. Wiliam, Inside the black box: Raising standards through classroom assessment. Phi Delta Kappan, 2010.
[31] Blackboard, [Online]. Available: http://www.blackboard.com/index.html [Accessed: 20-Jun-2018].
[32] PowerShell, [Online]. Available: https://docs.microsoft.com/en-us/powershell/ [Accessed: 20-Jun-2018].