A web service-based architecture for virtual labs in academic institutions

البنية قائمة على خدمات الويب للمعامل الافتراضية في المؤسسات الأكاديمية

أ. حسن خليفة محمد . محاضر بقسم علم الحاسوب . كلية الآداب والعلوم. سلوق- جامعة بنغازي.

أ. بدر محمد آدم. محاضر مساعد بقسم تكنولوجيا معلومات . كلية العلوم والتقنية قمينس.

أ. فرج أحمد محمد . مساعد محاضر. كلية العلوم والتقنية قمينس.

MA: Hassan Kh. Mohammed. Lecturer, Department of Computer Science. College of Arts and Sciences. Salouq - University of Benghazi.
Email: hasanelfakhari@uob.edu.ly

MA: Badr M. Adam. Assistant Lecturer, Department of Information Technology. Qminis College of Science and Technology
Email: baderalbarhame40@gmail.com

MA: Faraj A. Mohamed. Assistant Lecturer . Qminis College of Science and Technology.
Email: faragahmed202020@gmail.com

تاريخ تسليم البحث	تاريخ قبول البحث
2022 / 9 / 24	2022 / 10 / 22

الملخص: البنية القائمة على خدمة الويب للمعامل الافتراضية هي بنية قائمة على السحابة تهدف إلى استخدامها في المؤسسات الأكاديمية كبديل موثوق للمختبرات المادية الحالية. تحاول هذه الدراسة التوصل إلى بنية منهجية من شأنها أن تقدم بديلاً جيدًا للوضع الحالي في مختبرات المؤسسات الأكاديمية. سيتضمن سيناريو الحلول المقترحة اهتمامات العميل والخادم المتعلقة بالإجراءات والعمليات في المختبرات الأكاديمية. سيعمل هذا النموذج المقترح على تكييف Ruby لبرمجة العملاء وجانب الخادم، و SOAP كمعيار لتبادل الرسائل يدعم اتصال الخدمة، و WSDL كواجهة خدمة، و WS-BPEL لتحديد تكوين الخدمة.

الكلمات المفتاحية: الحوسبة السحابية، التعليم الإلكتروني، المعامل الافتراضي، التعليم العالي، علوم الكمبيوتر، التعليم القائم على حل المشكلات.

Abstract: Web service-based architecture for virtual labs is a cloud-based architecture that intended to be used in academic institutions as a reliable alternative for the existing physical labs. This study would try to come up with a systematic architecture that would present a good alternative for the current situation in labs of academic institutions. The scenario of the proposed solutions would include the client and server-side concerns related to the procedures and processes in the academic labs. This proposed model will adapt Ruby for programming the clients and the server side, SOAP as a message exchange standard that supports the service communication, WSDL as a service interface, and WS-BPEL to define service composition.

Keywords: Cloud Computing, PaaS, IaaS, E-Learning, Virtual Lab, Higher Education, Computer Science, Problem Based Learning.

1. **Introduction:** The Internet provides a distributed infrastructure for sharing information globally with an estimation that the online population reached 7,875 billion users in 2021 with an 1,331.9 % increase between 2000 – 2021 (source: internetworldstats.com). The very large user market becomes a great motivation for new technologies enabling one to build the next generation of Web based applications. In particular, it is very attractive to develop collaborative applications linking of the growing number of diverse clients with rich media Web content.

This evolution brings fundamental changes to our society in communication and knowledge acquisition pattern ─ anytime, anywhere, people no longer have to meet face to face to communicate while all information is delivered to the client interface online and on demand. The new trend comprises innovative technological features: it offers a platform facilitating ubiquitous access of desktop, PDA and cellular phone (Windows, MacOS, UNIX, Linux, and PalmOS) clients; it supplies an interface with services for easier availability to global resources including data, text, 2D and 3D graphics, video/audio stream, and MP3 music; it promotes an interoperable synchronization mechanism that captures interaction between participants ─ teacher and student, trainer and trainee for real time experience. [22].

1.1. Problem Statement

In this particular case, the objective of our study is to investigate the feasibility of adapting the existing cloud technology for doing the labs in academic context. This project is motivated by the need to understand the impact of using cloud-based programming labs as an alternative replacement for the traditional way of doing the programming labs through faculty labs. In faculty labs we need a number of computer hardware and software that is equal to the number of students who are enrolling in the programming course, while in the contemporary way of doing the same functionality utilizing the concept of cloud computing through PaaS or the so-called "Platform as a Service" we need only a number of terminals equals to the number of students enrolling the course. This is because the infrastructure that supposed to do the processing is provided by a third party through the Internet. Thus, we plan to measure the *responsiveness* and the *cost* of the proposed solution.

1.2. Research Question(s)

This proposed research would definitely answer the following questions:

- What benefit we get through integrating web services in academic labs procedures?
- How to develop a web service-based architecture for virtual academic labs?
- What type of toolkits could be used to facilitate this architecture?

1.3. Objective

Referring to the questions which has been highlighted in the Research Question section, this research proposal would find solutions for the problems given above in term of its objectives which are:

- To study the importance of integrating web services in academic lab procedures.
- To identify the procedures and course contents of the proposed web service-based architecture.
- To develop a commercialization toolkit model for virtual academic labs.

1.4. Scope

Purpose:

The suggested project would be focusing on e-learning in academic lab environment in Universiti Putra Malaysia (UPM) at least for the mean time. Since the outcomes and the successfulness are yet to be empirically evaluated, by using questionnaires, the project would be applied on UPM. Then by analyzing the results of the evaluation, the project might be implemented nationally and internationally respectively in logh run.

Perspective:

The perspective is from the point view of the researchers, teachers and students, i.e. the researcher, teacher or even student would like to know what are the systematic differences in the performance when we transform to the web service-based virtual labs.

Quality focus:
The main effect studied in the experiment is the responsiveness and the cost in cloud-based programming labs.

2. Literature Review

J. Cappos et al. [5] stated that it is important for students to gain the necessary skills to work with cloud-based resources. Moreover, there is a need for students' code to be run across different operating systems and architectures without change. Also students need to build algorithms for inter-machine interaction (like a global store or a DHT). Researchers hypothesize that Seattle project would be able to help students in gaining the skills to work with cloud-based resources and enable them build their programs for different Oss and architectures without change. The proposed architecture which consists of many components (sandbox, node manager, experiment manger) is empirically developed to be adapted in the real world using the existing cloud-based infrastructure. Therefore, the used methodology is Data Analysis through "Experimentation". In the LR section, the researchers mentioned some criteria when comparing the system in hand with the existing ones, such as: 1. Flexibility to support donated resources. 2. Cost. 3. Availability. 4. Scalability and locality. 5. Scope of system concepts.
Wen-Wei Liao and Rong-Guey Ho [6] applied observational Learning in the Cloud Education System of Art Education. Art creation skills, such as long creation process, massive information, complicated computing, and the difficulty to learn from others' works, are complicated and difficult to memorize. Moreover, there is a need for high speed computing and massive storage of observational learning systems. The researchers assume that applying blended learning in teaching and developing observational learning system combined with traditional classroom teaching would assists the students in observational learning and help them to understand the students' observational learning process. This study tried to apply observational learning of social learning theory in the curriculum of art education in an elementary school through developing a cloud education system to assist instruction and thus this study expected to utilize computer to assist in the instruction. Subjects were the on-line observational learning group who used the cloud education system and the other group served as the general observational learning group who used traditional painting tools. Therefore, the methodology used is Data Analysis through "Experimentation". 1. Image expression ability. 2. Color expression ability. 3. Expression ability of space treatment. 4. Aesthetic expression ability. 5. Completeness ability.
Chenyang Yan [7] outlined in his paper how to build a laboratory cloud for computer network education. A successful computer network practical course requires not only a well-designed class but also a full range of facilities with necessary maintenance. Unfortunately, it is not easy to achieve this objective due to constraints which can be summarized as follows: lack of enough devices, restricting the experimental procedures due to security and privacy issues, and high lab maintenance cost in time and effort. The researchers created a versatile "Virtual Computer Network Lab" and supposed that this proposed system would solve the addressed problems and come up with a new solution that: provides less lab administration cost and higher lab availability, provides more open, engaged lab learning environment, and provides more flexible practical assignments design. The researchers built the proposed architecture and made the experiment environment that allowed them to test the performance of this network infrastructure through instructor survey and learner survey. So the used methodology is Data Analysis through "Experimentation". For instructors: stability and responsiveness, convenience and time, class design, results of assignments, and teaching experience. For Students: learn and understand material, reaction speed, and enjoyment. For both:UI use, readability of documentation, outlining of assignments, functionality and operability of virtual devices.
EduCloud: PaaS versus IaaS Cloud Usage for an Advanced Computer Science Course was suggested by Luis M. Vaquero [8]. Evaluation of the educational potential of infrastructure and platform clouds has not been explored yet. Moreover, evaluation of which type of cloud would be the most beneficial for students to learn, depending on the technical knowledge required for its usage, is missing. The researcher hypothesized that: Cloud technologies can be useful in educational scenarios for computer science students by focusing students in the actual tasks at hand. Moreover, cloud platforms offer a significant improvement over the previous situation in labs where much effort was devoted to setting up the software necessary for course activities. Eighty-four

students carried out two lab experiments using three different setups. The first (IaaS) uses an IaaS cloud for the provision of VMs, the second (PaaS) uses a PaaS cloud to host student software, and the third (control) is similar to previous years' settings where students were in charge of the whole setup. Therefore, the paper follows the Data Analysis Methodology through Experimentation and Surveys. The researchers basically aim at comparing IaaS, Control, and PaaS techniques in term of two measurements which are: usefulness and Ease of Use.
R. Guin et. al [9] proposed a smart architectural concept for making of a university education system using cloud computing paradigm. Governments spend huge amount of budget to upgrade the condition of university in every year either by constructing new ones or employing good faculties at any cost. However, in spite of this good effort by the governments, it is seen often that only the amount gets spent, but no benefit at all especially regarding costs and quality of education system. The researchers assume that using their proposed model, not only the government will be benefitted having spent comparatively lower cost to universities, but also the quality of education system would be raised undoubtedly to some extent. The researchers proposed a model which aims at utilizing the limited resources in a most efficient and cost-saving way. So the research methodology they followed is "Formal methods". The researchers compared their model to existing ones in term of: user data security, availability of data, knowledge back up, economic feasibility, e-learning, safety against piracy.
Jun Xiao et [10] aim in their study at building intelligent education cloud service platform not only can meet the demands of the development plan, but also can help to build a smart or intelligent city. The researchers proposed a "Mobile Class" system as a part of the cloud learning service platform, and they assume that it will support learners' autonomy in learning across terminals under the interactive environment of the Internet. They build the system with the cooperation the Shanghai Lifelong Learning Network and test and analyze its design functionalities using the empirical methods. Therefore, the methodology used is Data analysis through experimentation. They measure the following: instructional design (navigation, progress marker, feedback to learners), interface design, interaction design, and technical design.
GAURAV BHATIA et.al [11] proposed an implementation of cloud computing technology in Indian Education System. Indian government devoted huge amount of budget for many years in order to uplift the education system in India. However, the problem is still exist. One of the major reasons is the lack of centralized system for the government to check the educational institutes in which not only the year end result produced is checked but it consist of throughout monitoring of all the education institutes in India. The lack of distribution of resources like teaching tools, teaching stuffs etc. The researchers propose that that with the help of cloud computing technology the addressed deficiencies can be overcome and the government can reach the goal of hundred percent literacy rates and the goal to provide quality education to each citizen of India. The researches clarify some terminologies related to cloud computing. Then they explain the architecture of this technology and how it works. After that, they produce the model that can be adapted by the Indian government. Moreover, they put the strategy that must be followed to achieve the goals of the system.
Le Xu et. al [12] proposed Cloud-Based Virtual Laboratory for Network Security Education. Hands-on experiments are essential for computer network security education. Existing laboratory solutions usually require significant effort to build, configure, and maintain and often do not support re-configurability, flexibility, and scalability. Researchers hypothesize that their cloud-based virtual laboratory education platform called V-Lab would provide a contained experimental environment for hands-on experiments using virtualization technologies (such as Xen or KVM Cloud Platform) and OpenFlow switches. Researchers proposed the architecture of the system and then applied this model in the real world through three-phases teaching model then evaluate this model with six factors. So, we can say that they followed the Data analysis through experimentation. The factors used for experiment evaluation are: motivation, knowledge, collaboration, creativity, demonstration, and feedback.
Chen Dongyi and Zhang J ixian [13] did Research on Construction of the Public Service Platform in Life-long Education Based on the Cloud Computing. The public service platform of life-long education is a very important link to construct life-long education system, as it is not only the necessary technical support to undertake life-long education, but also the concrete demonstration of it in the innovation of concept, innovation, method, service and so on. The paper takes the theoretical research named "based on modem distance education, construct

the theory and empirical study of life-long learning system" as the guidance and advanced modern IT as the support, besides, it constructs a public service platform of life-Iong teaching in line with Zhejiang's development of life-long education and all sorts of teaching. The researchers build software model of public service platforms which is guided by social and all people's demands in study, which effectively integrates the two technical frameworks of Elearning and M-Iearning. Besides, it contributes to the share and integration of multiple learning models, learning resources and learning platforms, thereby constructing a u-learning environment which integrates multiple ecological systems. Therefore, they follow the formal proving methodology.

Nikita Yadav et. al [14] developed an intelligent cloud for higher education. Faculty and students do research and need quality data while students of a particular field need a subject-oriented knowledge. Manually getting these kinds of data is time consuming as students depend on literature, books, different kind of software and hardware. The researchers assume that using artificial intelligence based cloud computing in higher education would improve quality and ease the process of getting e-resources. The researchers made their cloud smarter by using Artificial intelligence techniques. They proposed a framework of an AI based cloud service models for higher education that will help in cutting the costs spent on buying resources. Therefore, the used methodology is “Formal logic”. The researchers compared their AI cloud model to a traditional simple cloud model in terms of: scalability of time demands peaks, compatible reusability, automatic update, and prediction ability.

3. Background of the study

3.1. E-learning

E-learning (or eLearning) is the use of electronic media and information and communication technologies (ICT) in education. E-learning is broadly inclusive of all forms of educational in learning and teaching. E-learning is inclusive of, and is broadly synonymous with multimedia learning, technology-enhanced learning (TEL),computer-based instruction (CBI), computer managed instruction, computer-based training (CBT), computer-assisted instruction or computer-aided instruction(CAI), internet-based training (IBT), web-based training (WBT), online education, virtual education, virtual learning environments (VLE) (which are also called learning platforms), m-learning, and digital educational collaboration. These alternative names emphasize a particular aspect, component or delivery method.

E-learning includes numerous types of media that deliver text, audio, images, animation, and streaming video, and includes technology applications and processes such as audio or video tape, satellite TV, CD-ROM, and computer-based learning, as well as local intranet/extranet and web-based learning. Information and communication systems, whether free-standing or based on either local networks or the Internet in networked learning, underly many e-learning processes.

E-learning can occur in or out of the classroom. It can be self-paced, asynchronous learning or may be instructor-led, synchronous learning. E-learning is suited to distance learning and flexible learning, but it can also be used in conjunction with face-to-face teaching, in which case the term blended learning is commonly used. [15].

3.2. Cloud Computing

According to NIST (The National Institute of Standards and Technology): Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and s services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model is composed of five essential characteristics, three service models, and four deployment models. [18]

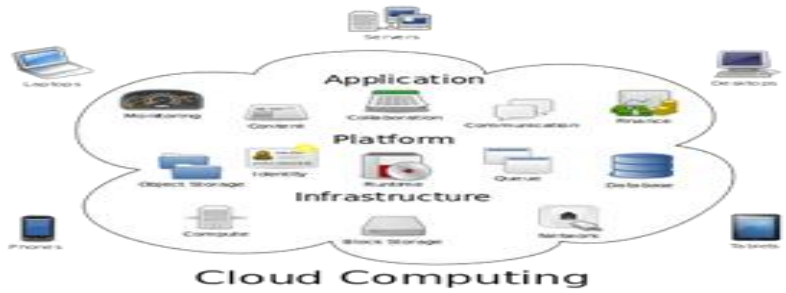

Figure 1 Architecture of Cloud Computing

Essential Characteristics:

On-demand self-service.

A consumer can unilaterally provision computing capabilities, such as server time and network storage, as needed automatically without requiring human interaction with each service provider.

Broad network access.

Capabilities are available over the network and accessed through standard mechanisms that promote use by heterogeneous thin or thick client platforms (e.g., mobile phones, tablets, laptops, and workstations).

Resource pooling.

The provider's computing resources are pooled to serve multiple consumers using a multi-tenant model, with different physical and virtual resources dynamically assigned and reassigned according to consumer demand. There is a sense of location independence in that the customer generally has no control or knowledge over the exact location of the provided resources but may be able to specify location at a higher level of abstraction (e.g., country, state, or datacenter). Examples of resources include storage, processing, memory, and network bandwidth.

Rapid elasticity.

Capabilities can be elastically provisioned and released, in some cases automatically, to scale rapidly outward and inward commensurate with demand. To the consumer, the capabilities available for provisioning often appear to be unlimited and can be appropriated in any quantity at any time.

Measured service.

Cloud systems automatically control and optimize resource use by leveraging a metering capability1 at some level of abstraction appropriate to the type of service (e.g., storage, processing, bandwidth, and active user accounts). Resource usage can be monitored, controlled, and reported, providing transparency for both the provider and consumer of the utilized service.

Service Models:

As suggested by figure 2, there three service models that are delivered by cloud computing.

Software as a Service (SaaS).

The capability provided to the consumer is to use the provider's applications running on a cloud infrastructure. The applications are accessible from various client devices through either a thin client interface, such as a web browser (e.g., web-based email), or a program interface. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited user-specific application configuration settings.

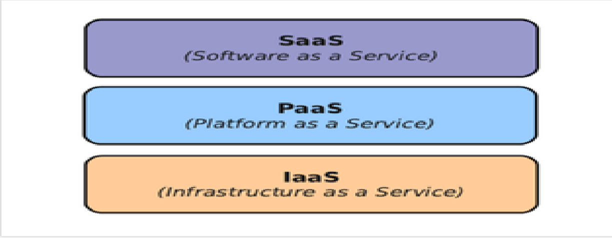

Figure 1 Cloud Computing Stack

Platform as a Service (PaaS).

The capability provided to the consumer is to deploy onto the cloud infrastructure consumer-created or acquired applications created using programming languages, libraries, services, and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, or storage, but has control over the deployed applications and possibly configuration settings for the application-hosting environment.

Infrastructure as a Service (IaaS).

The capability provided to the consumer is to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, and deployed applications; and possibly limited control of select networking components (e.g., host firewalls). [15].

3.3. Service Oriented Architecture

Service Oriented Architecture (SOA) is a paradigm for organizing and utilizing distributed capabilities that may be under the control of different ownership domains and implemented using various technology stacks. In general, entities (people and organizations) create capabilities to solve or support a solution for the problems they face in the course of their business. It is natural to think of one person's needs being met by capabilities offered by someone else; or, in the world of distributed computing, one computer agent's requirements being met by a computer agent belonging to a different owner. The term owner here may be used to denote different divisions of one business or perhaps unrelated entities in different countries.

There is not necessarily a one-to-one correlation between needs and capabilities; the granularity of needs and capabilities vary from fundamental to complex, and any given need may require a combination of numerous capabilities while any single capability may address more than one need. One perceived value of SOA is that it provides a powerful framework for matching needs and capabilities and for combining capabilities to address those needs by leveraging other capabilities. One capability may be repurposed across a multitude of needs.

SOA Figure3 is a "view" of architecture that focuses in on services as the action boundaries between the needs and capabilities in a manner conducive to service discovery and repurposing.

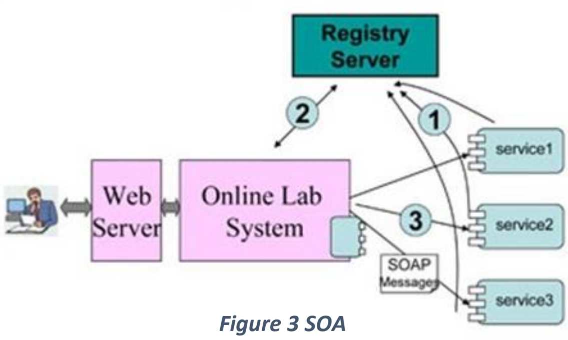

Figure 3 SOA

Requirements for SOA

Figure4 below shows an example of an information system scenario that could benefit from a migration to SOA. Within one organization, three separate business processes use the same functionality, each encapsulating it within an application. In this scenario, the login function, the ability to change the user name, and the ability to persist it are common tasks implemented redundantly in all three processes. This is a suboptimal situation because the company has paid to implement the same basic functionality three times. [19].

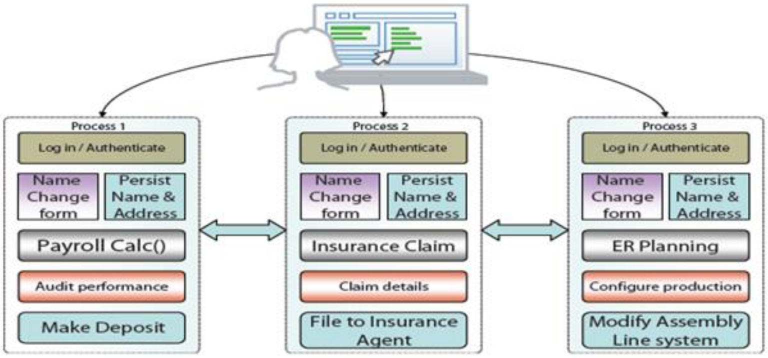

Figure 4 information system scenario

3.4. Web Services

Web services extend the World Wide Web infrastructure to provide the means for software to connect to other software applications. Applications access Web services via ubiquitous Web protocols and data formats such as HTTP, XML, and SOAP, with no need to worry about how each Web service is implemented. Web services combine the best aspects of component-based development and the Web, and are a cornerstone of the Microsoft .NET programming model. [20].

The goal of the Web Services Activity is to develop a set of technologies in order to lead Web services to their full potential. The Web Services Activity Statement explains the W3C's work on this topic in more detail. [21].

Figure 5 information system scenario

4. Methodology. The adopted methodology to develop the proposed web service-based labs would implement some web application programming formalities. There are many approaches; however, we focus on building the proposed architecture and then implement it using Ruby for client – server programming and interactions and WSDL for web services modelling.

Since we need to build a new system for academic labs that relies mainly on network and cloud to support the functionalities and procedures of the real labs in universities and academic institution, we have to devote a reasonable time in collecting the necessary information about the current situation because this will enable us to simulate the real functionalities and combine them in the new project.

5. Significance and Contribution

The proposed system would play a significant and an important role in order to help academic institution transfer to cloud-based environment when conducting their scientific labs. The new system would open gates wide for these institutions to get benefit of the new era technology of web services which intends to be reliable and flexible. In addition, the system would provide a systematic manner to manage all the processes that are in the real labs in the new environment in order to achieve the highest utilization of network resources in these institutions.

6. Summary and Conclusion

This study aims to evaluate the transition to a cloud-based programming lab environment. It examines the consequences of adapting the new technology of cloud computing in the academic situation. However, the context of the study still small and need to expanded to cover more academic situations.

This effort supposed to be helpful to the researcher in exploring the impact of Cloud Computing in the UPM alumni. The decision makers at the faculty can utilize the results when planning or deciding to transit to the cloud-based solution.

To accomplish this work, a literature review of the previous efforts need to be explored more in a comprehensive manner to get benefits of the previous experience. Moreover, a specific budget must be dedicated by the faculty for the requirements of the execution.

7. References

- Claes Wohlin, Per Runeson, Martin H¨ost, Magnus C. Ohlsson, Bj¨orn Regnell, Anders Wessl´en. *"Experimentation in Software Engineering"* E-book. Springer-Verlag Berlin Heidelberg 2012.
- .M. Parizi et al., *Empirical evaluation of the fault detection effectiveness and test effort efficiency of the automated AOP testing approaches*, Inform. Softw. Technol. (2011), doi:10.1016/j.infsof.2011.05.004.
- Rafael Cano-Parra et al., *Cloud-based Simulation for Education: An Illustrative Scenario*, First International Conference on Technological Ecosystems for Enhancing Multiculturality (2013)
- E. Aljenaa et al., *Towards An Efficient E-Learning System Based On Cloud Computing*, Second Kuwait Conf. on E-Services and E-Systems, April 5-7, 2011
- J. Cappos et al., Seattle: *A Platform for Educational Cloud Computing*, SIGCSE'09, March 3–7, 2009, Chattanooga, Tennessee, USA.
- Wen-Wei Liao, Rong-Guey Ho, *Applying Observational Learning in the Cloud Education System of Art Education in an Elementary School*, 11th IEEE International Conference on Advanced Learning Technologies, 2011.
- Chenyang Yan, *Build A Laboratory Cloud for Computer Network Education*, The 6th International Conference on Computer Science & Education (ICCSE 2011) August 3-5, 2011. SuperStar Virgo, Singapore.
- Luis M. Vaquero, *EduCloud: PaaS versus IaaS Cloud Usage for an Advanced Computer Science Course*, IEEE TRANSACTIONS ON EDUCATION, VOL. 54, NO. 4, NOVEMBER 2011.
- R. Guin et. al, *A smart Architectural concept for making of a University Education System using Cloud Computing Paradigm*, World Congress on Information and Communication Technologies, 2011.
- Jun Xiao et. al, *Design and Implementation of Cloud-Learning Service Platform*, IEEE/WIC/ACM International Conferences on Web Intelligence and Intelligent Agent Technology, 2012.
- GAURAV BHATIA et.al, *Implementation of Cloud Computing Technology in Indian Education System*, ICCCNT12 26th_28th July 2012, Coimbatore, India.
- Le Xu et. al, *Cloud-Based Virtual Laboratory for Network Security Education*, IEEE Transactions On Education, 2013.
- Chen Dongyi and Zhang J ixian, *Research on Construction of the Public Service Platform in Life-long Education Based on the Cloud Computing*, The 8th International Conference on Computer Science & Education (ICCSE 2013), April 26-28, 2013. Colombo, Sri Lanka.
- Nikita Yadav et. al, *Developing an Intelligent cloud for Higher Education*, ACM SIGSOFT Software Engineering Notes January 2014 Volume 39 Number 1.
- http://en.wikipedia.org/wiki/E-learning

- http://www.slideshare.net/vodqanite/why-average-response-time-is-not-a-right-measure-of-your-web-applications-performance-nishant-verma.
- http://searchcloudcomputing.techtarget.com/photostory/2240178755/Thirteen-cloud-service-providers-to-watch-in-2013/3/CloudBees#contentCompress
- http://csrc.nist.gov/publications/nistpubs/800- 145/SP800-145.pdf
- http://www.adobe.com/enterprise/pdfs/Services_Oriented_Architecture_from_Adobe.pdf
- http://msdn.microsoft.com/en-us/library/ms950421.aspx .
- http://www.w3.org/2002/ws/
- Xiaohong Qiu and Anumit Jooloor, *Web Service Architecture for e-Learning*
- https://www.mulesoft.com
- Jahan Hassan, Anamika Devi, Biplob Ray, Virtual Laboratories in Tertiary Education: Case Study Analysis by Learning Theories. 2022.