Developed and Taught Course Modules to Enhance Cloud Computing Education

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Abstract: Cloud computing (CC) is emerging as a promising solution to businesses and individual users. In order to effectively teach knowledge of CC we have developed three course modules, one education tool, and one real world project. These modules have been successfully taught in COMP 621 Web Security course in Spring 2011, Spring 2012 and Spring 2013 in the Department of Computer Science at XXXX. Our experience exhibits that teaching these modules helped students not only understand the need of CC, but also gained significant knowledge of CC and security architecture. Through a laboratory exercise and a real world project students gained hands-on experience. Students' survey and feedback reflected that these modules and the laboratory exercise are very valuable in their educational experience. These modules and hands-on laboratory exercise could be used in software engineering, networking, Web security and other first year graduate level courses.

1 INTRODUCTION

Cloud computing provides flexible information technology infrastructures and configurable software services, reduces costs, enables business innovation and many others benefits. The service that cloud computing provides has become a commodity; when companies like Amazon, Intel, Google develop new applications, they sculpt cloud computing into the product they will produce. Several cloud computing systems have been developed by the industry, such as Amazon Elastic, Amazon EC2, Google Apps, etc. (Amazon Web Services, Google 2010). As a result expectations for Information Technology (IT) workforce have been increased by rapidly expanding cloud computing applications. It becomes an urgent task to teach knowledge of cloud computing to computer science students, so that they can meet the industry's expectation for the next generation IT professionals.

Most Computer Science, Information Management System, and Software Engineering curriculums do not adequately prepare students for such expectations. Based on demand three cloud computing course modules have been developed and taught, and the hands-on laboratory exercise has been designed and used in the Department of Computer Science at XXXX. In this paper, we present these new course modules titled "Introduction to Cloud Computing", "Introduction to Cloud Computing Services", "Security Architecture for Trustworthy Cloud Computing", one education tool, one hands-on laboratory exercise and one real world application project, and discuss our teaching experience. In section 2 the learning objectives and outcomes will be discussed. The details of these modules will be presented in section 3. A hands-on laboratory exercise will be specified in section 4. In section 5 a real world application project will be given. In section 6 teaching and evaluation results will be presented. The conclusion and future work will be discussed in section 7.

2 LEARNING OBJECTIVE AND OUTCOMES

Cloud computing is expanding rapidly. As a result it increases the expectations for IT professionals. In order to prepare students for IT workforce and for them to effectively learn knowledge of cloud computing we have developed three course modules. The learning objective of these modules is to enhance the computer science curriculum by providing information and technology that are related to cloud computing and cloud computing security. Instructors can teach these modules in

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computer science senior classes or first year of graduate courses.

After attending the lecture of these modules, conducting a laboratory exercise and completing the assigned project students should be able to 1) understand the need for cloud computing, 2) gain significant knowledge of cloud computing architectures, characteristics and benefits, service models, deployment models, enabling technologies, data storage and operating system, and 3) apply learned knowledge to real world applications.

3 THE COURSE MODULES

Three courses modules have been developed that are "The Introduction to Cloud Computing", "Introduction to Cloud Computing Services", and "Security Architecture for Trustworthy Cloud Computing". We used three hours to teach the module 1, three hours for module 2 and two hours for module 3.

3.1 Module 1: Introduction to Cloud Computing

In this module, basic concepts, characteristic, benefits, enable technologies, service models and several cloud computing architectures are introduced.

In the basic concepts section we first answer the question why we need cloud computing. Cloud computing has the promise to provide all of businesses, or single user needs such as storage, computations, and applications in the mass, and the end user decides what they would like to have. With the increased demand for defining and molding cloud computing into something that is not that easily defined causes companies like Google, Salesforce, IBM to become very aggressive in terms of producing the product fast in order to be the inimitable leader. This causes a need for other companies like Twitter, Facebook to evolve and adapt in order to keep up with and hopefully exceed the pack of competing companies.

Secondly we briefly give the definition of clouding computing by introducing several definitions. One concept from Simon Wardley's "Cloud computing-Why it matters" presented at OSCON 09 was "Cloud Computing is a generic term used to describe the disruptive transformation in IT towards a service based economy driven by a set of economic, cultural and technological conditions" (Wardley, 2009). We use a graphic image to display the concept of cloud computing. Cloud computing can be defined as a paradigm in which a system utilizes the virtualized resources of networks of computers to handle a systems workload. A hypervisor must be a part of the system (Choi, 2009).

We present several existing systems to help students understand the architecture of cloud computing. First we introduce the architecture in a basic and simple way. A cloud computing environment consists of clients, the datacenter and the distributed servers (Velte et al., 2009). We use Amazon Elastic Computer Cloud (EC2) as an example because Amazon EC2 is a web service that provides resizable computing capacity in the cloud. It allows the user to obtain and configure capacity with minimal friction. It provides a user with complete control of their computing resources and lets them run on Amazon's proven computing environment. Amazon EC2 changes the economics of computing by allowing the user to pay only for capacity that they actually use (Amazon Web Services).

We discuss five main characteristics of cloud computing in this module. These characteristics are On-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service. On-demand self-service implies a consumer can unilaterally provision computing capabilities. Broad network access has capabilities that are available over the network and accessed through standard mechanisms that promote use by heterogeneous thin or thick client platforms. Resource pooling gives the provider's computing resources which 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. Rapid elasticity can be quickly and elastically provisioned, in some cases automatically. To the consumer, the capabilities available for provisioning often appear to be unlimited and can be purchased in any quantity at any time. Measured service demonstrates cloud systems automatically control and optimize resource use by leveraging a metering capability at some level of abstraction appropriate to the type of service. Resource usage can be monitored, controlled, and reported providing transparency for both the provider and consumer of the utilized service (Mell et al., 2009).

We also discuss three service models that are Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS) in this module (Choi, 2009). SaaS gives users the capability to use the cloud provider applications running on a cloud infrastructure. PaaS gives users everything that they need to develop, test, and deploy applications to the cloud. IaaS is delivery of the computing infrastructure as a fully outsourced service, versus an in-house, capital investment-sourced model (Mell et al., 2009).

We introduce three key enabling technologies that are virtualization, hypervisor and Web services in this module. Over the last several years, virtualized technologies have become a standard in the world of computers. These technologies, including the virtual machine, are software implementations of computer systems which partition hardware into high-level abstractions. This allows for resource sharing within the cloud along with more affordable, flexible and scalable hardware services (Wang et al., 2008).

Virtualization can be looked at as the abstraction of computer resources from the actual computer which can successfully allow databases, middleware, and operating systems to practically run anywhere. Cloud computing paradigm allows workloads to be deployed and scaled-out quickly through the rapid provisioning of virtual machines or physical machines. Service virtualization combines and slices business services deployed independent of the operating systems, programming language or hosting location. An intermediary cloud gateway sits between the producer and the consumer and aggregates the Web Service Description Languages.

When software is run on a virtual machine, the bits representing the programs instructions run through a layer of software that simulates a dedicated server infrastructure. This layer of software is known as the hypervisor. Hypervisors allow servers to run a single instance of software that serves multiple clients at a time, without needing to rewrite the software. They also allow operating systems and applications to install a consistent hardware profile (Yu et al., 2012). Web services today are frequently just Application Programming Interfaces (API) or web APIs that can be accessed over a network, and executed on a remote system hosting the requested services.

3.2 Module 2: Introduction to Cloud Computing Services

In this module we discuss data storage as a service, software as a service, and cloud computing operating system.

Commonly known as Storage as a Service (StaaS) cloud computing presents a solution for any user's need with its robust infrastructure that far exceeds the needs of any user with an internet connection. StaaS allows users to store data at remote disks and access them anytime from any place (Wang et al., 2008). User's data is stored on remote storage systems that are maintained by a third party. The data is then accessible through the Internet.

Cloud storage as of today comes in many different architectural designs. A cloud based storage system connects the user to their stored information through a web application that allows the user to create, store, and file all the information chosen (Wang et al., 2008). This design shows where the user works on the application layer uploading files to the cloud, the software service then distributes the uploaded information to three separate storage locations for disaster recovery. The application, which is the web portal or interface to the cloud storage, allows users to subscribe to the web cloud storage. Copies of the files that the user submits are then transferred over the Internet to cloud storage servers.

We use Amazon S3 (Simple Storage Service) as an example to explain how StaaS works. Amazon S3 is a platform that allows for cloud storage to users on any scale from one gigabyte to thousands of exabytes. With low cost, scalability and reliability Amazon S3 can meet any software developers' needs [Amazon Simple Storage Service].

A cloud computing operating system (OS) provides an interface for developing and deploying massively scalable distributed applications on behalf of a large number of users and exploiting the seemingly infinite CPU, storage, and bandwidth. Traditional Operating Systems are used to manage hardware components within the computer. The cloud OS relies on distributed processes that manage the cloud resources. A cloud OS is similar as a traditional OS that is a collection of scheduler, virtual memory allocator, file system code, interrupt handlers, etc. to regulate the access by software to CPU, memory, disk, and other hardware peripherals. A cloud OS provides an additional set of functionalities to give administrative access to resources in the cloud. A cloud OS also provides a set of network-based interfaces that applications can use them to query the management system and control cloud resources (Pianese et al. 2010).

The Architecture of the cloud operating system consists of two separate spaces that are the User Space and Kernel Space (Pianese et al. 2010). The cloud's kernel space is used to regulate physical allocation, access control, accounting and measurement of resources within the cloud's space. The cloud's user's space contains processes that are directly used by users.

Virtual Machine (VM) Management is the process that controls the allocation and de-allocation of virtual machines. Through the authentication kernel access rights are granted to the VM Management Kernal. This kernal is responsible for mapping an object name with its network address and port number. Catching all signals from the cloud OS, objects in the cloud user space are called and handled through this process.

Distributing processes is a key to provide abstraction and flexibility to computing resources from its physical nodes; this can be done with the use of Virtual Machines. Support for multiple OS's on the same hardware presents isolation to a certain extent between processes running on different VMs. Dynamic allocation on the cloud is done at two locations, the cloud process level migrates single processes between nodes while the VM level uses check pointing which can restore a VM state on a different node. Access control is controlled by a factotum server running on every machine, dedicated to authenticate the users resulting in a single sign on facility. The cloud user space contains libraries of API's that can be manipulated and changed to scale the application to satisfy different specifications just by updating a minor amount of embedded cloud library parameters (Pianese et al., 2010).

The cloud user space helps developers in two ways. One is eliminating the need for a developer to implement his or her own custom libraries, but instead use the cloud library API's and customize them. Secondly updating cloud library parameters for different specifications results in reusability of application components.

Software services known as SaaS (Software as a Service) identifies the use of computing power on a huge scale such as the cloud where companies can access applications and large amounts of virtual computing software without buying it. A service request is sent to the actual cloud service provider through a high level design. The web services architecture has three roles: a cloud provider, an application execution requestor, and a broker/mapper. The provider creates the web service and makes it available to clients who want to use it. An application requestor is a client application that consumes the web service. The mapper provides a way for the provider and the requestor of a web service to interact. The provider, requestor, and broker interact with each other through the operations of publish, find, and bind. A provider informs the broker about the existence of the web service by using the broker's publish interface to make the service accessible to clients. The information published describes the service and specifies where the service is located. The requestor consults the broker to locate a published web service (Lu, 2010).

3.3 Module 3: Security Architecture for Trustworthy Cloud Computing

Many security technologies have been proposed and developed to enhance cloud computing security. In this module we use Cisco Secure Data Center Framework as an example to discuss security issues. Cisco Secure Data Center Framework is one of them that provides multiple security layers and applied different existing security technologies to enhance cloud computing security [Bakshi].

Cisco has developed the Cisco Secure Data Center Framework with many security and trust considerations. The first consideration is general security issues. In this framework traditional security issues of information assurance such as data access control, encryption, and incident detection are integrated. The second consideration is access control that means an enterprise has capability to directly manage how and where data and applications are deployed and used. The third consideration is compliance and service-level management (SLA). It includes contracting and enforcement of service level agreements between different parties, legal issues, regulation and industry requirements, etc. The framework consists of Threat Profile, Cloud Data Center Visibility, Cloud Data Center Protection, Cloud Data Center Building Blocks, Cloud Data Center Control, Cloud Data Center Compliance and SLA. The Threat Profile contains threat models such as Service Disruption, Intrusion and Takeover, Data Leakage, Data Disclosure, Data Modification, Identity Theft and Fraud, etc. The Cloud Data Center Visibility provides various functions such as intrusion detection, anomaly detection, packet capture, network data collection and monitoring as well as event analysis and correlation. The Cloud Data Center Protection is very straightforward and provides different protection techniques and mechanisms such as stateful firewall access control, intrusion prevention, content filtering, and enforces endpoint and baseline security. Cloud Data Center Control deals many issues with how data being control. Because data are centralized in Cloud Computing it increase the possibility of insider threats, therefore a compartmentalization strategy is important. The data encryption policy must be in place for customers and providers. For an administrator, who accesses and controls virtualized operating system, must be strong authenticated. The Cloud Data Center Compliance and SLA deal with how the data being handled is controlled. So certain requirements are set in place by the consumer and provider in order to reach an agreement to make sure requirements for both are met. The service level agreement is in place to enforce these requirements and to make sure that the consumer and provider remain compliant [Bakshi].

4 A HANDS-ON LABORATORY EXERCISE

A key issue for students learning cloud computing knowledge and apply it to real world applications is to get hands-on experience. We have developed a deployment education tool and a one hour laboratory hands-on exercise to help students learn related knowledge and use cloud computing platforms.

4.1 Using Microsoft Windows Azure Platform

There exist many cloud providers. All of which have platforms associated with the deployment of applications to their cloud environment. Each provider implements its cloud service in order to cater to the needs of clients.

We selected Microsoft Windows Azure as our cloud platform. This platform provides and maintains control of an integrated development and hosting environment to allow software developers to easily create, manage, scale, and host applications through Microsoft datacenters. Applications are executed using Azures compute services, while storage is handled by the storage services; both of which are built on top of a component known as the Windows Azure fabric, which ties all services together and monitors applications to maintain desired states (Chappelle, 2008). These services are the main components of Windows Azure, shown in Figure 1. Specifically, a few of the responsibilities of the Azure fabric is to create new VM's and assign them to processor cores, run instances of an application, and detect when a instance has failed.

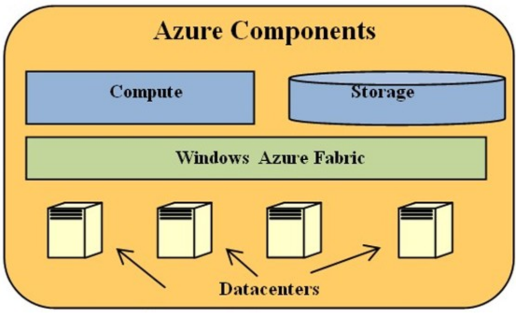

Figure 1: Windows Azure components.

4.2 Designing and Implementing an Education Tool

We designed and implemented an education tool named Scientific Utility for Cloud Harnessing (SUCH) (Yu et al. 2012). This tool provides functions to successfully deploy scientific applications to the Windows Azure cloud platform in a less complex manner than other methods, thus helping students to get hands-on experience of using cloud services. SUCH consists of three main components that are the deployment manager utility, the message queue, and the worker role. These components are shown in Figure 2. All of these components work together to upload, execute, and manage deployments within Windows Azure.

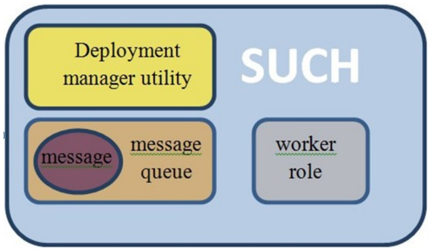

Figure 2: SUCH components.

The deployment manager utility allows students to upload files as well as manage services and applications utilizing the cloud. When the deployment manager is executed, it initiates cloud components, uploads files, and creates, starts, stops, and deletes deployments. To execute it, users must navigate to the Azure Application executable file located in Azure Deployment Manager folder in SUCH. The Message Queue utility builds messages, and stores them on the message queue for the worker role. It is composed of three programs: RunScienceCodeMessage.cs, a bucket class used to create message objects for the message queue, PopulateMessage.cs, which creates message object instances, initiates the message queue in Azure, serializes messages and populates the message queue, and ClearMessageQueue, which clears the message queue of messages. The Worker Role, located in the Application Worker Role folder, first uses an infinite loop to check the queue for instructions. If a message is located, the worker role takes it from the queue and executes message instructions with the assistance of Azure components.

SUCH provides a simple means of utilizing the vast resources within the cloud, thus students can avoid many unnecessary complications. It is user-friendly; students can join the laboratory lecture, read a few pages of instructions, complete set up and configuration steps, then they can execute their applications in the cloud.

4.3 Developing a Hans-on Laboratory Exercise

We developed a one hour hands-on laboratory exercise to help students understand how Microsoft Windows Azure works, how to develop and deploy an application to a cloud system. We wrote a document titled “User Manual for Using Microsoft Windows Azure and SUCH”. It describes all details of ten steps to guide students using Microsoft Windows Azure and SUCH.

First students must sign up for an account and downloading the Windows Azure SDK. Then students should download the SUCH zip file containing Clear Message Queue, Populate Message Queue, Application Worker Role, and Azure Deployment Manager. Students need to create an IIS management certificate and upload it to Azure via the management portal. They must fill in storage credentials into the values in the setting property of the SUCH worker role. Students need to generate a package file via the publish function in the SUCH worker role. Once the file is generated, they navigate to the Publish folder in the Application Worker Role folder, copy the configuration and service package files, and move them into the Debug folder of the Deployment Manager Utility Folder. Once those steps are completed, students must fill in account name, account key, etc. for the configuration files in the populate message queue, clear message queue, and deployment manager utilities. The file intended to be executed in the Azure should then be uploaded to Azure storage. Finally, users simply run the AzureDeploymentManager.exe, which will progress through a sequence of steps which enable successful application deployment. As SUCH executes, students can navigate to the online Azure management portal to view the creation, starting, stopping, and deletion of deployments. Figure 3 shows the Azure management portal as a deployment is in its Starting phase.

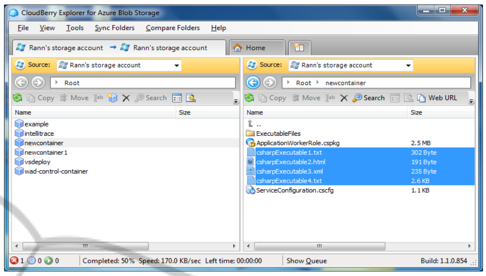

Figure 3: Output files created from executed applications within Azure.

In order to deploy to Azure, all executable applications must be uploaded to blob storage using CloudBerry Explorer for Azure Blob Storage. Using CloudBerry Explorer, a student would navigate to the Release folder location in the bin section of each folder that the executable file is located in. Next the student would execute SUCH and wait until the deployment has fully started. Once the deployment is ready, the student would fill the Populate Message Queue configuration file with information specifying the name of the executable files to be executed in Azure, location of each of the executable files in Azure storage, and the expected output file. After SUCH successfully runs, studnets should check their storage container to see if a new output file was created and uploaded to the cloud storage.

4.4 Getting Hands-on Experience

After students attend the lectures of the new course modules they are required to attend the one hour hands-on laboratory exercise. In the laboratory, we briefly introduce the functions of Microsoft Windows Azure and how to use the Scientific Utility for Cloud Harnessing. Then we guide students to go through installation and create a configuration file. We have developed several small application examples to let students to deploy them and to run these examples in Microsoft Windows Azure according to the steps that are described in 4.3. One application example is that prints a message to a text output file and fills an array with random numbers, then sorts the array in ascending and descending order, and displays the results in the output file. The results are shown in Figure 4. The output text file first displays a message explaining the functions of the program such as ‘creates an array of a user specified number of elements’. The next line displays an array of 50 elements, containing random numbers between 0 and 1000. The line after that displays the sorted array in ascending order, and the last line displays the sorted array in ascending order.

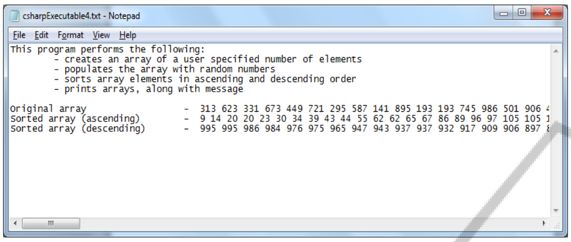

Figure 4: The output file.

Because COMP 621 Web Security is a graduate class most students (about 80%) can follow the instruction to deploy and run the sample program successfully. Some students need Teaching Assistants help.

5 A REAL WORLD APPLICATION PROJECT

Another key issue for students learning cloud computing knowledge and applying it to real world is to let them develop an application and run it in an existing cloud computing platform. Using this method students learn how to solve a real world problem and how to use a cloud computing system, and reduce the gap between classroom and the real world.

We assigned a real world application project to students. Two or three student formed a team. We provided detailed information about Microsoft Windows Azure, such as Azure account management, Azure services, configuration and package files, etc. to students. The project consisted of four major phases. In phase I each team developed a real world application program and executed it on a local computer. The program could be a hotel reservation system, a car dealer system, a student information management system, etc. In phase II students used SUCH to deploy the developed application to the Microsoft Windows Azure. In phase III students executed the application in the Microsoft Windows Azure and putted output information into a data file. In phase V students checked their storage container (via Cloudberry) to see if a new data file was created and uploaded to storage in the cloud. Each team must hand in a project report that included how the program was developed, how they deployed the program to the cloud, and the executed result. We also required every team to demonstrate their project in the class and exchange experience with other students within ten minutes.

6 RESULTS

We have successfully taught three course modules in COMP 621 Web Security class in the Department of Computer Science at XXXX in Spring 2011, Spring 2012, Spring 2013 and received excellent results.

Eighteen students took this course in Spring 2011, twenty-six in Spring 2012 and sixteen in Spring 2013. The students were very excited about learning the new emerging technology of cloud computing. To evaluate the students’ reactions and get feedback for teaching these modules we conducted a pre and post surveys at each semester. These surveys were in addition to the university course evaluation. The survey consists of two groups. The first group contains eight questions that reflected knowledge level of students. These questions are 1) basic knowledge of cloud computing, 2) knowledge of characteristics, service models and enable technologies, 3) knowledge of architectures, 4) knowledge of data storage services, 5) knowledge of operating systems, 6) knowledge of application software services, 7) knowledge of threats, and 8) knowledge of security mechanisms. Students’ ratings could be very low, low, medium, high, and excellent. The Spring 2013 survey results are displayed in Figure 5. Blue color represents pre-survey and red color represents post survey. For the pre-survey majority of the students gave a very low rating for their knowledge of characteristics, service models, enable technologies, architectures, deployment models, application software services and security mechanisms of cloud computing. The results varied more for students’ knowledge on data storage services, operating systems and threats of cloud computing, while majority of students seemed to have basic knowledge of cloud computing. No students rated their knowledge as High for any questions in the pre-survey. The post survey results show that students learned cloud computing and improved their knowledge levels. They had big improvement in their knowledge of characteristics, service models, enable technologies, architectures, data storage services, operating systems, threats, and security mechanisms of cloud computing. The second group are general questions that are 9) these modules help you gain knowledge of cloud computing and security related issues, and 10) you are more knowledge about cloud computing, threats and security mechanisms. Students could select Strongly Agree, Agree, Neither Agree or Disagree, Disagree, or Strongly Disagree. 100% students selected agree or strongly agree for all questions in the second group. Students felt these modules stimulated their interest to learn more about cloud computing. Most students enjoyed the hands-on laboratory exercise.

7 CONCLUSIONS

This paper presents three new cloud computing course modules titled “Introduction to Cloud Computing”, “Introduction to Cloud Computing Services” and “Security Architecture for Trustworthy Cloud Computing”, an education tool, a hands-on laboratory exercise and a real world application project assignment. These modules cover the basic concepts, architecture, characteristics and benefits, service models of cloud computing. These modules also discuss virtualization, hypervisor, Web services of enabling technologies, deployment models and cloud computing operating systems. Microsoft Windows Azure was selected as the cloud platform for the hands-on laboratory exercise. An education tool, Utility for Cloud Harnessing was developed to provide functions to deploy applications to the Windows Azure cloud platform in a simple manner, was used. A hands-on laboratory exercise has been developed to guide students to deploy and run an application in the Azure cloud platform step by step. Finally a real world application project was assigned to students.

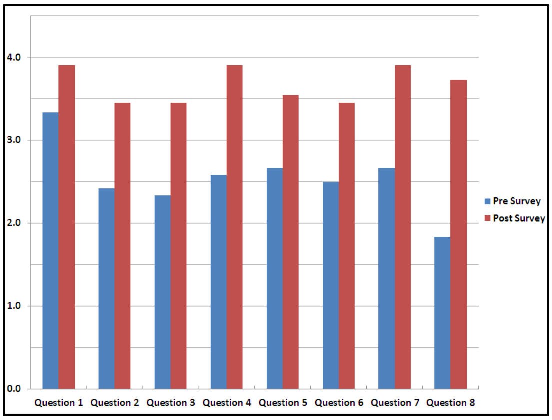

Figure 5: Spring 2013 Surveys.

We have successfully taught these modules in COMP 621 Web Security course in Spring 2011, Spring 2012 and spring 2013. Students’ survey and feedback reflected these modules are very valuable. They felt the module stimulated their interest to learn more about cloud computing. Our experience exhibits that combining lectures and hands-on laboratory exercise together can successfully integrate education and real world application into cloud computing education. The lectures bring new technology to students; let them learn the knowledge and applications of cloud computing. The hands-on laboratory exercise demonstrates how to deploy and run an application in an existing cloud platform, helps students understand functions of a real world cloud computing system and learn how deploying and running an application on the cloud platform, and lets students gain important insights into how applying learned knowledge into a real world. Assigning a real world application as a project helps students understand the difference running an application on a local computer and on a cloud computing system, increases their capability to solve complicated problems and breaks barriers between education and real world applications. Our experience also proves that teaching cloud computing modules is beneficial to students through both theory and hands-on experience, helps them learn advanced technology and apply learned knowledge to real world applications.

In order to satisfy the high demand of cloud computing professionals we are developing a course titled “Cloud Computing and Security”. We will offer this course in Fall 2014.

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REFERENCES

Amazon Web Services, DOI=http://aws.amazon.com/ec2/

Google 2010 Google Apps, DOI=http:// code.google.com/apis.

Wardley, S., 2009. Cloud Computing-Why it Matters. *O’Reilly Open Source Convention.*

Choi, P., 2009. How to Develop an Effective Security Strategy to Play in the Public Cloud. *Cloud Computing Journal.*

Velte, T., Velte, A. and Elsenpeter, R., 2009. Cloud

Computing A Practical Approach. McGraw-Hill.

Mell, P. and Grance, T., 2009. The NIST Definition of Cloud Computing. Version 15, October 7, 2009.

Chappelle, D., 2008. Introducing the Azure Services Platform. *Microsoft Corporation.*

Wang, L., Tao, J. and Kunze, M., 2008. Scientific Cloud Computing: Early Definition and Experience. *In Proceedings of 10th IEEE International Conference on High Performance Computing and Communications.*

Wu, J., Ping, L., Ge, X., Wang, Y. and Fu, J., 2010. Cloud Storage as the Infrastructure of Cloud Computing. *In Proceedings of IEEE Int. Conf. on Intelligent Computing and Cognitive Informatics*.

Amazon, Amazon Simple Storage Service, DOI=http://aws.amazon.com/s3/faqs/#What_can_I_do_with_Amazon_S3.

Pianese, F., Bosch, P., Duminuco, A., Janssens, N. Stathopoulos, T. and Steiner, M., 2010. Toward a Cloud Operating System. *In Proceedings of IEEE Network Operations and Management Symposium*.

Lu, X., 2010. An Approach to Service and Cloud Computing Oriented Web GIS Application. *In Proceedings of IEEE International Conference on Internet Technology and Applications*.

Bakshi, K. Cisco Cloud Computing - Data Center Strategy, Architecture, and Solutions. DOI=http://www.cisco.com/web/strategy/docs/gov/CiscoCloudComputing_WP.pdf .

Yu, H., Rann, J. and Zhan, J., 2012. SUCH: A Cloud Computing Management Tool. *In Proceedings of the 5th IFIP International Conference on New Technologies, Mobility & Security*.