TITLE

Virtualized Computational Environments on the Cloud to Foster Group Skills through PBL: A Case Study in Architecture

ABSTRACT

The ODISEA platform provides Virtualized Computational Environments (VCEs) on cloud providers as the computational infrastructure to support educational activities. A VCE consists of a collection of one or more Virtual Machines (VMs) to which the students connect from their own computers. In this paper a case study is presented in the architecture domain where a PBL activity is carried out in working groups. The study involves 293 students organized in 28 pilot groups that use customized VCEs created and deployed through the ODISEA platform on a Cloud, and 30 traditional groups that use a LMS platform. The VCE provides the software, hardware and specific configuration to ease the interrelation and cooperative work between the working groups, enhancing the process tracking and feedback gathering as well as providing a better organization of the teaching material. The results demonstrate that the VCE allows to improve the cooperative work, improving the final marks in the PBL developed by the pilot working groups. Also, an economical study is presented, highlighting the economic benefits of the Cloud with respect to traditional physical laboratories of PCs.

Keywords: Cooperative Work, PBLs, Cloud Computing, Virtualization

1. Introduction and background

Nowadays, students and employers agree on the importance of developing and evaluating in classrooms the skills that allow the student to acquire the competences required in their future jobs. For this, in the European universities, the implementation of academic degrees fostered by the European Higher Education Area (EHEA)[1] are centred around competences. This has encouraged teachers to design new curricula that incorporate innovative active learning methodologies that lead students to more realistic scenarios and, therefore, improving the development of the skills in the classrooms. As a consequence, in the last years, the EHEA has invested great efforts to identify and standardise the skills and competences required in the business market through the European Skills, Competences, Qualifications and Occupation (ESCO) [1] classification.

In this framework centred around competences, the cooperative work is identified as a common competence to all areas of engineering, and should be developed through specific methodologies that must be implemented by activities that fulfill these requirements [2][3]: a) Positive interdependence; b) Face-to-face Interaction; c) Accountability; d) Sharing known skills; e) Collaborative skills; f) Monitoring Process. One of the most used methodologies to develop the cooperative work between the students is Project Based Learning [4] (PBLs) since it allows to effectively integrate the aforementioned requirements [5].

Traditionally, PBL is a methodology used in the classroom in subjects related to architecture and construction [6]. In these areas in particular, but also in engineering, the new technologies have eased the application of PBLs in face-to-face [7], blended learning [8] and on-line [9][10] education. This involves using Computational Environments (CE), to provide students with access to virtual laboratories or software simulators (such as simulations to support the evaluation process of urban design projects [11]), or specific software tools (such as Architrave to analyse building structures [12]). These CEs provide hardware, software and specific configuration to involve the students in more realistic scenarios through specific activities. This is key to perform the stages planned at PBLs and develop soft skills [13] such as collaborative work.

The use of CEs to support the computational infrastructure required to perform educational activities faces some challenges, especially in areas such as construction and architecture since they are not closely related to computer science. From the lecturer point of view [14] there is an inherent difficult for professors on managing these CEs, who

[1] The European Higher Education Area (EHEA). http://www.ehea.info

very often end up resorting to the IT departments of their institutions, which may not provide the degree of flexibility required by the professor. Also, the professors usually require deterministic environments and reproducible CEs so that they create consistent clones of CEs that are guaranteed to satisfy the hardware, software and configuration requirements for their educational activities across several academic years. From the student point of view [15] there exists challenges to be solved, such as the ubiquitous and network access to the CEs, which is not always possible. However, the usage of CEs introduces many advantages for the students which include, but are not limited to: i) the ability to access anywhere and anytime the CEs and ii) removing the restriction imposed by physical laboratories of computers, where students are allocated time slots during the week to perform these activities. Finally, from the point of view of the educational centres [15], the acquisition and maintenance of the CE is not always affordable due to the large costs required to invest in new infrastructures to comply with the requirements in the classrooms (number of students, complexity of CEs, etc.).

The use of cloud technology is appropriate to resolve or minimize the aforementioned problems and challenges since it shows many advantages for the main stakeholders in education [16]. From the point of view of the lecturer, cloud solutions allow to create Virtualized Computational Environments (VCE) that can be easily cloned and redeployed should a failure happen (e.g. student actions that result in a misconfigured VCE). Also, the lecturers can deploy reproducible environments on-demand for their students in an elastic and scalable manner [17][18] and package the virtual environments for later use (e.g. other courses) [19]. From the students point of view, cloud computing provides students with ubiquitous access to the VCEs where the educational activities are performed to develop practical skills [20] or soft skills like teamwork [21] and, in addition, they can be available 24x7 [16]. From the educational centres point of view cloud technology represents an opportunity to rationalize the way computational and storage resources are managed to avoid unnecessary investments in new computational resources [22][23]. In spite of these benefits, cloud computing also raises concerns about privacy and security, especially with sensitive student data, provider lock-in, performance issues and licensing models of software [16][24]. These concerns can be overcome by on-premises Cloud Management Platforms such as OpenNebula or OpenStack, instead of using public cloud providers such as Amazon Web Services (AWS) or Microsoft Azure.

In previous works, the authors introduced a cloud platform named ODISEA [14][15]. This platform deploys VCEs on public and on-premises clouds in order to support educational activities. A VCE consists of a collection of one or more Virtual Machines (VMs) on top of computational resources to which the students connect from their own computers to carry out a certain educational activity. For example, students may require to connect using Remote Desktop to a VM based on Windows, running on a public cloud provider, customised to offer certain software and lab material required for the educational purpose. ODISEA manages the lifecycle of VCEs and paves the way for educators to dynamically deploy VCEs, accessible anywhere and anytime, to support their educational activities with an unprecedented degree of flexibility when compared to traditional physical laboratories and reducing the maintenance budget of Physical Hardware Resources (PHRs) for VCEs. Basically, ODISEA defines recipes that describe the software, hardware and configuration that are used to deploy and configure VCEs on top of different cloud providers, thus overcoming the barrier of provider lock-in.

In this work, by means of a case study in architecture, the authors want to go a step further presenting the ODISEA platform not only as a provider of computational infrastructure to support educational activities but also as a mechanism to improve the development of PBL in working groups. In this scenario, the professor uses a web-based application provided by ODISEA in which the VCEs are defined by high-level recipes, in order to express the hardware, software and configuration requirements to apply the PBL that involves cooperative work. The VCEs are automatically provisioned and configured from any of the major cloud platforms, with a single click of a button, in a matter of minutes. These VCEs are consistent replicas out of the recipes and so, there is a guarantee that the very same computational environment is properly deployed regardless of the number of VCEs used and the time when they were deployed.

The case study has been performed in the mandatory subject (6 ECTS) of Electrical Installations (INEL) in the third course of the Fundamentals of Architecture degree at the anonymous university, in Spain. In the study, 293 students have been involved and distributed in 58 working groups (between 4 and 6 students). The study defined 28 pilot working groups that used customized VCEs managed by ODISEA to develop a PBL activity, and 30 working groups that used the traditional method through conventional laboratories with PCs and using a Learning Management system (LMS) platform based on Sakai [25]. A comparative study between working groups is presented that shows the positive impact of the VCEs deployed on a cloud provider in the PBL activity, assessing the supervision and feedback obtained from the PBL by the lecturer and in the students final marks. Also, a voluntary subjective questionnaire was passed to students of pilot groups concerning aspects related to the employed method for the feedback used by the lecturer, the interrelation and the cooperative work among working groups, availability and ubiquitous access of resources required to develop the PBLs and the general opinion about the experience. Finally, an analysis of the economic impact produced by the use of the VCEs is presented, demonstrating that the use of ODISEA is beneficial not only for the student and lecturer but also for the institutions that have to maintain or invest in IT infrastructures.

2. Materials and Methods

First, this section addresses the method to use the ODISEA platform for creating and managing VCEs in the pilot working groups for the case study and provides also a brief explanation of the on-premises cloud employed. After that, it introduces a description of how the PBL activity is carried out, describing the stages of the PBL and outlining the material, hardware and software required in each stage. After that, the distribution of working groups (pilot and traditional groups) is shown. The next subsections describe the main differences between the execution method of the PBL activity in traditional and pilot working groups due to the use of the VCEs concerning the issues related to the progress tracking by the professor and feedback obtained for the PBL, the interrelation and cooperative work of the working groups, the material organization and the software resource access. Finally, this section includes the questionnaire that was designed to evaluate the subjective opinion of the pilot group students about the issues commented above.

2.1. ODISEA Platform Methodology

To perform the PBL activity in pilot groups several VCEs were required. To deploy them, the ODISEA[2] platform was employed (see Figure 1), an open-source platform for professors to dynamically manage VCEs across their lifecycle, creating virtual computational environments specifically configured to support educational activities such as those carried out in INEL in each stage of the planned PBL activity. VCEs are a set of virtual machines running on the hardware of a Cloud provider. The educational institution may decide to deploy a Cloud Management Platform, such as OpenNebula or OpenStack, thus turning the institution into an on-premises cloud provider. Alternatively, the professor may decide to outsource the computing requirements to a public cloud provider, which allow provisioning computational storage and network capacity on a pay-as-you-go basis.

To use ODISEA, the following steps had to be performed:

1. The professor responsible for an educational activity defines the hardware, software and configuration requirements of the VCE to be used in the activity (step 1 in Figure 1.) and communicate this information to the ODISEA administrator.

[2] ODISEA is available at http://www.grycap.upv.es/im/usecases.php#odisea

2. If required, a system administrator applies the software requirements into one or several Virtual Machine Images (VMIs). These VMIs include a combination of an Operating System and a set of applications together with their configuration. These VMIs will be created for the specific cloud. An alternative procedure is to include in the templates that describe the VCE the software requirements and let ODISEA perform the unattended installation of the software (step 2).

3. The administrator communicates the credentials to the professor to access the web interface of ODISEA (step 3).

4. The professor deploys a set of VCEs either temporarily for a specific activity or for a longer time frame (e.g. a whole semester) by means of the web interface provided by ODISEA (step 4).

5. The students connect to the VCEs via internet using remote desktop or SSH connections (step 5).

6. When the activity is completed, the professor terminates the VCE (step 6).

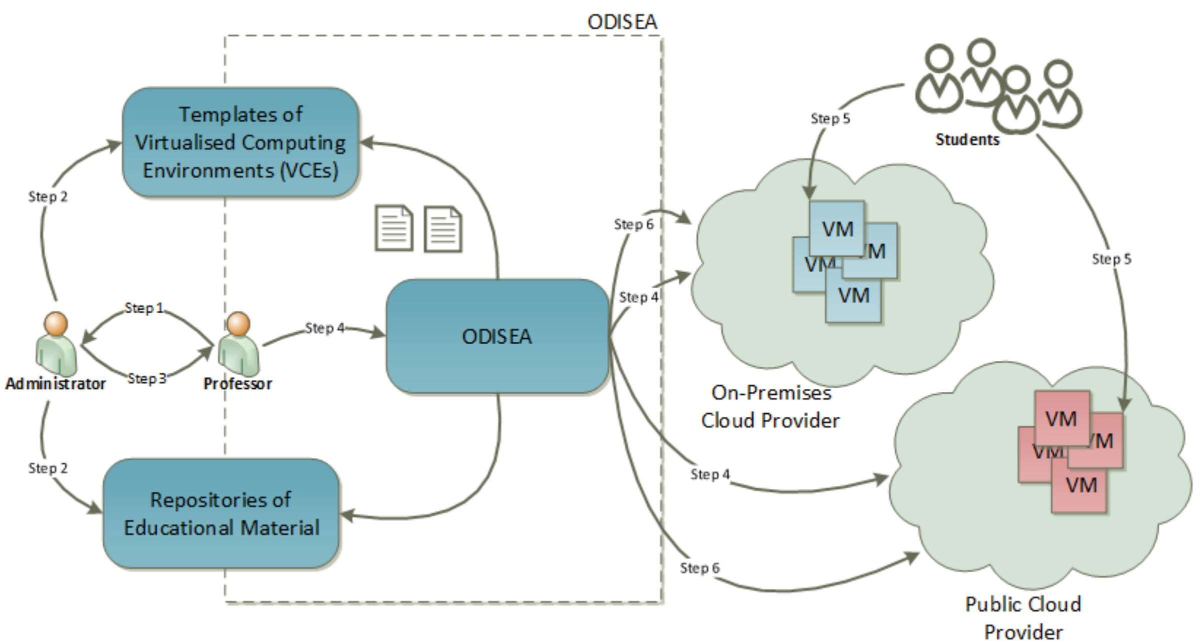

Figure 1. Big Picture of the ODISEA Methodology for deploying VCEs

Notice that this platform can seamlessly deploy the VCEs on on-premises cloud providers and public cloud providers. This means that the very same VCE will be deployed out of the same template regardless of the cloud provider choice. This gives the professor an enhanced flexibility to deploy these remote labs environments on public clouds.

To perform the case study, we have used an on-premises IaaS Cloud platform with a total of 128 cores and 352 GB of RAM managed by OpenNebula 4.2 to provision the VMs required by the VCEs.

2.2. Electrical Installation Project

Table 1. Material, software, description and deliverables of each stage defined at the Electrical Installation project.

ID	Name	Material	Software	Description	Deliverable
1	Project Description and Total Power	-LVER-ITC-BT-10 (*) (pdf) -Base Plan (AutoCAD)	AutoCAD Office - Word PDF reader Web Browser	Review and study the building addressed in the project and calculate the electrical power of the building.	Summary sheet of the electrical power of the building.
2	Design of General Electrical Line	-LVER-ITC-BT-14 (*) (pdf) -Features and Sizing of Gel (pdf)	AutoCAD Office - Word PDF reader Web Browser	Design the general electrical line installation and calculate it.	Installation blueprint and memory with the calculations.
3	Design of Electric Meters	-LVER-ITC-BT-16 (*) (pdf) -Electricity Meter of Building (pdf) -Base Plan (AutoCAD)	AutoCAD Office - Word PDF reader Web Browser	Design the panel and the enclosure of the meters.	Blueprint of the panel meters and its enclosure, and a memory with the calculations.
4	Design of Individual Lines	-LVER-ITC-BT-15 (*) (pdf) -Features and Sizing of Users Lines (pdf)	AutoCAD Office - Excel PDF reader Web Browser	Design and calculate the individual electrical shunts of the building.	Blueprint with the layout of the lines and a memory (table) describing the calculations.
5	Design of home installation	-LVER-ITC-BT-25 (*) (pdf) -LVER-ITC-BT-27 (*) (pdf) - Electrofunctional Design (pdf) -Base Plan (AutoCAD) -"Electrical Buildings". V. Blanca, 2011. Ed. UPV (Book)	AutoCAD PDF reader Web Browser	Design of the home interior installation.	Blueprint that defines the electrical points of one of the houses that composes the block of flats.
6	Design of installation in communal areas	-LVER-ITC-BT-25(*) (pdf) -LVER-ITC-BT-27 (*) (pdf) -Base Plan (AutoCAD)	AutoCAD PDF reader Web Browser	Design of the common areas of the building.	Blueprint that defines the electrical points of the ground floor, the stairs and the garage.
7	Calculate Home Installation	-LVER-ITC-BT-25 (*) (pdf) -Calculation of the Internal Circuits (pdf link) -"Electrical Buildings". V. Blanca, 2011. Ed. UPV (Book)	AutoCAD Office - Word Office - Excel Pdf reader Web Browser	Calculate the interior circuits of the house.	Memory (table) describing the calculations.
8	Calculate Installation on Communal Areas and End of the Project	-LVER-ITC-BT-25 (*) (Pdf) -Calculation of Circuits Lighting (pdf link)	AutoCAD Office - Word Office - Excel PDF reader Web Browser	Calculate the circuits of the common areas.	Memory (table) describing the calculations.

(*) Low Voltage Electrotechnical Regulation (LVER)

The PBL activity that was employed for the case study was a realistic electrical Installation Project for a building composed of a block of flats. This is a significant project featuring common issues in professional architectural activity.

The PBL activity was composed of 8 stages (one session of two hours each one). Table 1 shows a summary of each stage indicating the material, software required, summary description of the activity and the deliverables defined.

2.3. Working Groups Distribution

To perform the case study, 28 pilot working groups (143 students) distributed in three classrooms (C1, C2 and C3) were created where they executed the PBL through a set of VCEs that were dynamically deployed on a cloud by means of the ODISEA platform. Also, 30 working groups (150 students) distributed in three classrooms (T1, T2 and T2) carried out the PBL in a traditional way without using VCEs. The six classrooms involved in the study were supervised by the same teacher and were assigned similar schedules in different days.

The information about the number of students in each working group is shown in Table 2. Notice that each group ranged from 4 to 6 students.

Table 2. Information about the distribution of the working groups in the classrooms.

PILOT WORKING GROUPS			TRADITIONAL WORKING GROUPS		
	Nº Members	Nº Groups		Nº Members	Nº Groups
C1	4	1	T1	4	5
	5	8		5	9
	6	0		6	0
C2	4	2	T2	4	0
	5	7		5	9
	6	0		6	1
C3	4	0	T3	4	1
	5	4		5	6
	6	6		6	0

2.4. Progress tracking by the professor and feedback.

In the PBL activity, a minimum compulsory attendance was set to 6 out of the 8 sessions. After every session, the working groups could voluntarily hand in the work done not later than 24 hours after the end of the session. The goal of these voluntary deliverables was to provide students with weekly feedback to enhance the quality of the project. The deliverables were reviewed by the lecturer pointing out the wrong issues and also comments about how the final project could be improved. After that, the working groups were encouraged to apply the improvements proposed by the lecturer.

In traditional working groups, the procedure to deliver the reports and to evaluate the work performed by the group did not easily allow the professor to periodically track the educational activities, since the professor did not have an easy way to know the real time evolution of the activities performed by each group. The student uploaded the deliverables into PoliformaT, the LMS platform based on Sakai [25], through tasks defined by the lecturer. However, the teacher did not have access to the folders where the students or working groups were generating the results. Instead, in the pilot working groups, the students performed the activities in the different VCEs, producing the deliverables and receiving the feedback from the professor through the shared folders provided by the platform named "Delivery of Works". These folders are shared with the professor through a file synchronization software called ActiveSync provided by Windows. This means that the content that students leave on those folders is automatically made available in a folder for the professor available on her desktop. This eases the procedure of providing feedback to students.

2.5. Interrelation and cooperative work of the working groups

In each stage of the PBL activity, the working groups had tasks to resolve both individually and in group. For this, creating the final deliverable required to manage intermediate results generated by all the members of the working groups. In traditional working groups, the procedure to share and interchange information was through shared filers provided by the LMS. With this approach, the students had to connect to the LMS platform via web browser, uploading and downloading the files involved. Each working group had a shared folder assigned in the LMS. Instead, in the pilot working groups, the students performed the activities in the different VCEs connected through remote desktop. This VCE had configured a "Shared Workspace" folder, where the students generated the intermediate results of the tasks during the different stages of the PBL. The students work as if the folder was a local shared folder, thus avoiding to upload and download files from the LMS, what results in speeding up the interaction among the students.

2.6. Software Resource Access

To perform the PBL activity different software resources were required. In traditional working groups, the software required to perform the stages was provided to the students in specific laboratories where the students could access the PCs with the installed software. The students could not access from their homes the required software to develop the project since, in some cases, they required licensed software that could only be employed in the computer labs within the campus. In the pilot working groups, students can access the VCE where all the software is installed and the hardware required from their own devices (PCs, Macs) connected to the Internet, both in-campus and off-campus. Since the VCEs are Virtual Machines running on an on-premises cloud platform within the university, the licensed software required for the activities can be used for academic purposes. Note that students do not require to install any software application other than the software required to connect to a remote desktop, which is available free for the major operating systems (Windows, macOS, GNU/Linux). This provides students with seamless access to the software required to carry out the educational activities.

2.7. Material Organisation

The PBL stages required to use diverse resources from different sources (Low Voltage Electrotechnical Regulation (LVER) defined by the government, technical PDF documents and books). In traditional working groups the LMS platform was used to store the educational materials but, still, no appropriate tool was found that provided a single unified view of all the materials for each lab session. Many students faced troubles when performing the calculations of the installations since they found difficulties accessing the different spreadsheets imposed by the regulations and also in the organization of the appropriate material to carry out the practice lessons. The students also found difficult to carry out the collaborative work out of the classroom due to the large amount of material they had to use (books, regulation, documents, etc.). Indeed, the materials came from different sources and there was no central place to access this documentation. However, in the pilot working groups a specific tool was used as a complementary software to LMS used. Each VCE was configured so that the web browser accessed by default a specific page created with Symbaloo [26], an online tool that we adopted to organize and index the materials for each lab session. The documents and books are still stored in the LMS but that web page represented a single entry point to all the information required coming from disparate sources, thus simplifying the work for the student. This fact considerably helps carrying out the activities in the different sessions, since the student is provided with all the required materials before starting the lab session. The labs lessons are, therefore, much more productive for students, who just have to focus on the work to be done in that specific session.

2.8. Subjective Questionnaire

A questionnaire was designed (see Figure 2.) to be filled in by the students of the pilot working groups after concluding the PBL activity. The goal of this questionnaire was to evaluate the experience of the student by means of specific questions related to the method for delivering results to the lecturer, interrelation and cooperative work of the groups, the availability of the resources, organization of the educational material, the satisfaction with the usage of the VCE and, finally, whether it contributed to increase the interest of the student in the subject.

	Totally Disagree	Disagree	Neutral	Agree	Totally Agree
Q1. The method to hand in the deliverables through the "Delivery of Works" folder facilitated the feedback with the professor.					
Q2. The VCEs employed to carry out the activities facilitated the interrelation and cooperative work of my group.					
Q3 I always had available the resources (software, hardware and educational material) required to perform the tasks in each stage of the PBL activity.					
Q4. The educational material has been well organized and directly accessible in each stage of the PBL activity through Symbaloo.					
Q5. Generally speaking, the PBL activity execution using the VCE has been a satisfactory experience.					
Q6. The general approach of the PBL activity using the VCEs has contributed to increase my interest for the subject.					

Figure 2. Questionnaire items

3. Results and Discussion

This section describes and discusses the results. First, the VCE created to perform the PBL in the pilot groups using the ODISEA platform is described. Second, a statistical study about the improvement in the progress tracking and feedback comparing traditional and pilot groups is assessed. Third, the improvement in the final marks comparing both set of groups is analysed. Fourth, the analysis of the answers obtained in the questionnaire presented above is included. Finally, an economical study about the cost of using the VCEs in a public cloud provider as opposed to maintaining a physical lab infrastructure of PCs is discussed.

3.1. Virtualized Computational Environment (VCE)

This section details the VCE created with ODISEA to carry out the stages designed in the PBL activity. Each pilot working group was assigned an instance of a VCE. Each instance of a VCE was shared by three pilot working groups, each one from a different classroom. This reduces the amount of required Virtual Machines and, at the same time, avoids the overlap of having multiple teams working on the same VCE, since class schedules are different for each group. However, notice that the working group can, and are encouraged to, freely use the VCEs anytime and anywhere. Having multiple teams working on the same VCE only impacts on the performance of the VCE that the students experience. An advantage introduced by the use of cloud computing is that we can dynamically deploy additional

VCEs on-demand, depending on the number of groups. This unprecedented flexibility enables to redistribute the working groups across additional VCEs in case further computational requirements are necessary.

Every VCE allows the student to have a remote desktop that provides access to all the software required to perform the activities designed in the PBL activity (see Table 3). The software offered can be free but also licensed, using the licenses offered by the university. The VCE also exposes the shared virtual spaces that allow the working group members to interact among themselves and with the professor.

Table 3. Software requirements of the VCEs.

SOFTWARE	LICENSE	DESCRIPTION
Windows 7 Prof + Multi-user access to Remote Desktop + ActiveSync	University	Operating System with the required software for remote user access.
AVG	Free	Antivirus
Chrome Browser	Free	Web Browser
Office 2010 Professional	University	Microsoft's Office Suite
Autodesk AutoCAD 2014 Win 64	University	Design software, drawing and geometry.
Adobe Acrobat Pro XI	University	Software to create, edit and update PDF documents
WinRAR 5.01 64	Free	Zip/Unzip files
Symbaloo	Free	Web Links Manager to better organize the material.

To create the VCE, the main steps indicated in section 2.1 were carried out, which are now detailed:

1. The professor specifies the hardware requirements (8 GB of RAM) together with the required configuration. Two shared virtual disk spaces (folders) have been defined that are shared only by the members of the working groups. These have been the "Shared Workspace", where the students have generated the results of the tasks done during the cooperative work and the "Delivery of Works", where the students have delivered the results of the stages and where the professor has produced the feedback and corrections of the tasks that are handed in on a weekly basis by the teams. This way, each team member has access to the feedback of the professor and the results that each individual team member has generated.
2. These specifications are sent to the ODISEA system administrator, who has deployed the set of VCEs with the established requirements.

3. The ODISEA system administrator gives the credentials to the professor so that the VCE can be deployed by the professor in the on-premises cloud of the university by means of a web-based portal (shown in Figure 3.).
4. The professor deploys 10 instances of VCEs in the cloud. Each instance is a customized Virtual Machine that, as mentioned earlier, supports three teams.
5. The students connect to the VCEs through remote desktop to perform the PBL activity.
6. In the last step, the professor collects and stores away the deliverables from the shared folders and terminates the VCEs. This frees the underlying used hardware resources on the cloud platform, to be used by other deployments made through ODISEA.

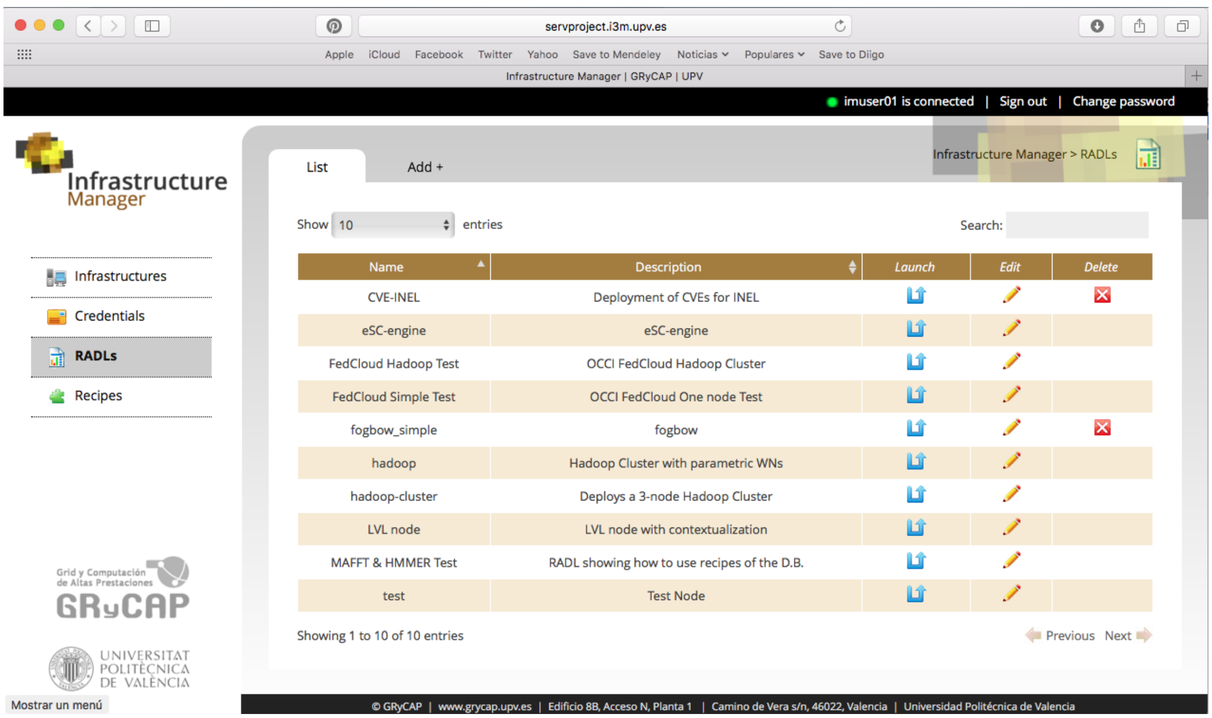

Figure 3. ODISEA interface to deploy the VCEs.

3.2. Progress Tracking by the Professor and Feedback Analysis

The progress tracking by the professor and feedback can produce an indicator to know if the working groups have done the planned tasks in each stage defined in the PBL and also to evaluate the motivation of the student to voluntarily make the deliverables in order to achieve better final marks in the PBL.

The PBL was composed of 8 stages, and each stage defined a deliverable (see Table 1). As stated earlier, the deliverables could be voluntarily handed in up to 24 hours after of the session assigned to the stage. These deliverables are revised by the professors in order to raise issues to be improved for students to achieve better marks.

Therefore, each team could potentially submit between 0 and 8 partial deliverables corresponding to each stage. This resulted in a maximum of 224 (28*8) deliverables in pilot groups and 240 (30*8) in traditional groups. The obtained results indicated that the pilot groups delivered 211 deliverables (87.91% of the maximum) and in traditional groups were delivered 177 deliverables (79.01% of the maximum).

Also, the averages of delivered deliverables were compared between traditional and pilot working groups. The average in pilot working groups were 7.54 and the standard deviation 0.69. It was higher than in traditional working groups where the average was 5.27 and standard deviation of 1.363. To discover if statistical differences existed, we considered two distributions: on the one hand grouping the number of delivered deliverables of each working groups, and the other hand grouping the delivered deliverables of each traditional working groups. The results indicated differences in the averages. To contrast if there was an statistical difference between distributions we used the SPSS software [27]. First, it was tested the normality of both distributions through the Kolmogorov-Smirnov [28] (K-S) test and a level of significance of 5%. The result of the K-S test was p=0.0000, rejecting the null hypothesis that the distributions were Normal. Therefore, we proceeded to perform non-parametric tests in the two independent samples. It was performed the Mann-Whitney U [29] (MWU) and a level of significance of 5%. The result of the MWU test was p=0.0000, rejecting the null hypothesis that both distributions belonged to the same distribution and indicating, therefore the existence of statistical differences between pilot and traditional working groups.

Table 4 shows the aggregated results concerning the partial deliverables. The table shows that in the pilot groups, 61,71% (17 working groups) made the 8 deliverables, and in traditional working groups only 10% (3 working groups) did. Furthermore, in pilot groups 35,71% (10 working groups) made 7 out of 8 deliveries and only 3.58% (one working group) made less than 7 deliveries. However, in traditional groups the results were more distributed, 26.57% (8 working groups) made 6 deliverables, 50% (15 working groups) made 5 deliverables, 10% (3 working groups) made 3 deliverables and 3,33% (one working group) made 1 deliverable. The fact that these deliveries where non-mandatory reveals the high degree of motivation of the students on the subject. Notice, however, that in pilot working groups 97,42% of the groups made 7 or more deliveries.

Table 4. Percentage of delivered deliverables by the working groups.

	PILOT		TRADITIONAL	
# of deliverables	**# of Working Groups**	**% Deliverables**	**# of Working Groups**	**% Deliverables**
8 out 8	**17**	**61,71%**	**3**	**10,00%**
7 out 8	**10**	**35,71%**	**0**	**0,00%**
6 out 8	**0**	**0,00%**	**8**	**26,57%**
5 out 8	**1**	**3,58%**	**15**	**50,00%**
4 out 8	**0**	**0,00%**	**0**	**0,00%**
3 out 8	**0**	**0,00%**	**3**	**10,00%**
2 out 8	**0**	**0,00%**	**1**	**3,33%**
1 out 8	**0**	**0,00%**	**0**	**0,00%**

A significant increment in the voluntary delivered deliverables has been demonstrated in the pilot working groups. This could be due to the use of the VCE because the method to deliver and manage progress tracking by the professor and feedback through shared folders was easier and more productive for the student. This approach allowed teachers and students to review the documents using the Track Changes tool provided by Microsoft Office. Also, the use of the VCE provided to the pilot working groups all software and hardware required to do and carry out the deliverables in an ubiquitous way and whenever they wanted. Indeed, the ability to easily customize the VCEs and to provide anytime anywhere access arises as one the main benefits of adopting cloud computing for these education scenarios.

However not all the traditional working groups had availability to access the software required (license, hardware requirements) since they had to go to specific laboratories of PCs to develop the deliverables. The access to these laboratories was limited because they were shared with other subjects and students only had free access to the laboratories in a given schedule.

We truly believe that providing an ubiquitous access to hardware, software and material by means of VCEs deployed on a Cloud platform eases to carry out the group and individual tasks avoiding the shortcomings of physical laboratories.

3.3. Final Marks Analysis

This section analyses the final marks in the PBL obtained by all working groups. Table 5 shows the number of students and working groups, average and standard deviation of each classroom involved in the study. Also, it shows the global average and standard deviation of pilot and traditional working groups.

Table 5. Descriptive parameters (average and standard deviation) of the final marks distributions in the pilot and traditional working groups.

CLASS	Nº STUDENTS	Nº GROUPS	AVERAGE	STD. DESVIATION	GLOBAL AVERAGE	GLOBAL STD. DEVIATION
T1	65	7	7.10	1.82		
T2	51	14	6.76	1.84	7.01	
T3	34	10	7.21	2.22		
C1	44	9	8.03	1.49		
C2	43	9	8.52	1.07	8.40	
C3	56	10	8.62	1.29		

In the analysis, the averages were compared. Table 5 indicates that the final mark averages in the pilot working groups were always higher when compared to that of the traditional working groups. To discover if statistical differences existed, we considered two distributions. On the one hand, grouping final marks of the pilot working groups, and the other hand grouping the final marks of the traditional working groups. A box-and-whiskers diagram of these distributions was generated (see Figure 4.) what suggested the existence of statistical differences.

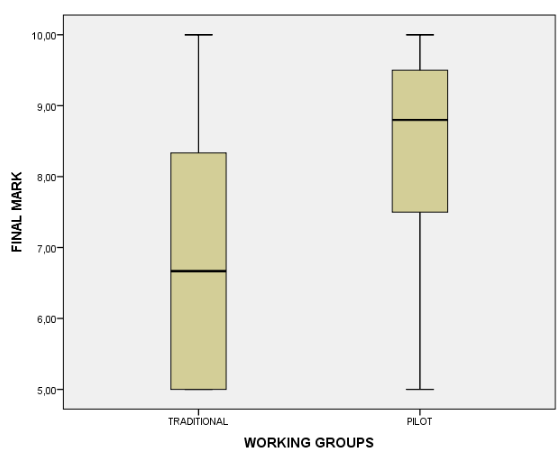

Figure 4. Box and whiskers diagram of final marks.

To contrast if there were statistical differences between distributions we used again the SPSS software. First, it was tested the normality of both distributions through the Kolmogorov-Smirnov (K-S) test and a level of significance of 5%. The result of the K-S test were p=0.0000, rejecting the null hypothesis that the distribution were Normal. Therefore, we proceeded to perform non-parametric tests in the two independent samples. It was performed the Mann-Whitney U (MWU) and a level of significance of 5%. The result of the MWU test was p=0.0000, rejecting the null hypothesis that both distributions belonged to the same distribution and indicating, and therefore the existence of statistical differences between pilot and traditional working groups.

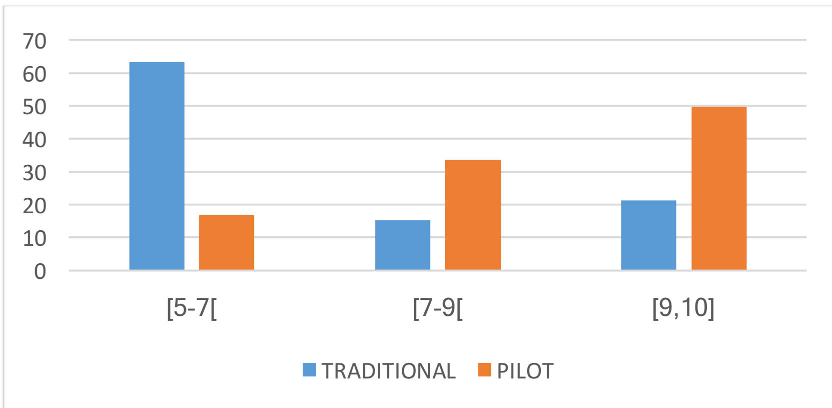

Figure 5. Final marks distributed by mark ranges

Another study was performed to determine the ranges of final marks where the differences appear. Figure 5. shows the number of students belonging to pilot and traditional working groups between the mark range [5,7[, [7,9[and [9,10]. It can be noticed that the major decrement exists in the range [5,7[in favour of the pilot groups (from 63% to 17%), moving these students to upper ranges. Therefore, we can observe an increment in the ranges of [7-9[from 15% to 34%, and [9-10] from 21% to 50%.

Another result that we considered important to point out in Figure 5. was that in the traditional groups the largest number of students accumulated in the range [5,7[, whereas in the pilot group the largest number of students accumulated in the range of [9,10]. Also, in the range of [7.9[, a significant increase was also observed in students belonging to pilot groups with respect to traditional groups.

3.4. Questionnaire Answers

A homogenous distribution of the students that answered the questionnaire across the classrooms was observed. Out of the total 83 students, 28 belong to classroom C1, 27 to classroom C2 and 28 to classroom C3.

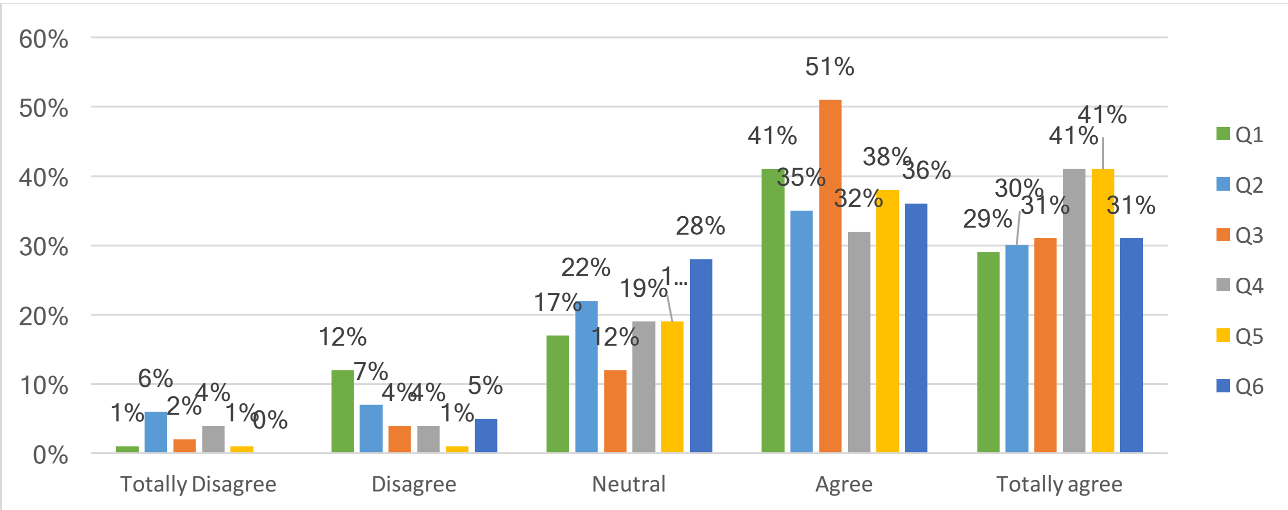

Figure 6. Percentage of answers of the questionnaire.

The first question of the questionnaire was "Q1. The method to hand in the deliverables through the "Delivery of Works" folder facilitated the feedback with the professor.". Figure 6. shows the answer of Q1 indicating that 70% of students considered that the use of the "Delivery of Works" shared folder configured in the VCE had facilitated the feedback with the professor. The percentage of negative evaluations was only 13%. These can be mainly attributed to the fact that they have to work in local folder and do not need any specific action to deliver the results. By not disrupting the common usage patterns of students with additional overhead (e.g. submitting files via the LMS, etc.) collaboration and interaction is easily achieved both for students and the professor.

The second question was "Q2. The VCEs employed to carry out the activities facilitated the interrelation and cooperative work of my group.". Figure 6. shows the answer of Q2 indicating that 65% of students considered that the use of VCEs had facilitated the interrelation and the cooperative work because it had provided the students with access to the resources required to perform the activities via a remote desktop (software, hardware and shared folders). Therefore, the usage cloud computing in the shape of customized computing resources has demonstrated to be convenient to carry out group skills [21], since percentage of positive evaluations was significantly greater than the negative evaluations. These can be mainly attributed to the fact that having all the resources easily available, deployed in a cloud platform, for each team member has encouraged students to contribute to the project. Therefore, the perception of the interrelation and cooperative work is positively considered by the students.

In addition, the professor had access to the folder "Shared Workspace" used by the students in order to periodically check the individual contributions and comments, including the early drafts before the actual delivery. This enables the professor to assess the cooperative work of the students as the project evolves.

The third question of the questionnaire was "Q3. I always had available the resources (software, hardware and educational material) required to perform the tasks in each stage of the PBL activity.". The target of this question was to evaluate the availability of computer resources to carry out their work. Figure 6 shows the results of Q2 indicating that 82% of students positively value the availability of resources in the VCE after finishing the PBL. There is also a very low percentage of negative evaluations.

Previous works have indicated that cloud computing is appropriate to provide 24x7 availability [16]. Indeed, students positively value having the resources available in the VCE and this is enforced as students gain more experience with the usage of VCEs. Indeed, students become aware of how helpful is to have available the VCEs anytime and anywhere, which allows them to manage their own schedule.

The fourth question was "Q4. The educational material has been well organized and directly accessible in each stage of the PBL activity through Symbaloo." and the goal was to evaluate the organization of the material and the documentation that they had. The results (see Figure 6) indicated that 73% of students after PBL positively valued the access and organization of the supporting material. Indeed, providing a centralized point of access to a wide variety of disperse educational resources is key for students to remain focused during the educational activity.

The fifth question was "Q5. Generally speaking, the PBL activity execution using the VCE has been a satisfactory experience." and the target was to evaluate in general terms the experience that involved cooperative work. The results (see Figure 6) indicated that the negative evaluations came from only 2% of students. Instead, positive evaluations were manifested by 79% of students for project. This points out that students are in favour of adopting the usage of tools that benefit their daily work as is the case of the VCEs during the educational activity. The fact that the complexity of the underlying technology (cloud computing, virtualization, configuration, etc.) is abstracted away by means of ODISEA allows the students to focus on the educational activity rather than on the tools involved to achieve that purpose.

The last question of the questionnaire was “Q6. The general approach of the PBL activity using the VCEs has contributed to increase my interest for the subject.”. The target of this question was to know if the perception of the students regarding the general organization of the projects (computer resources, supporting material, deliverables, etc.) contributed to increasing their interest on the subject. The results (see Figure 6) indicated that 67% of students after completing PBL believe that the way the project was developed contributed to increment their interest on the subject. This is very important since the students of the School of Architecture traditionally show little interest in subjects related to installations. Therefore, we believe that motivation of students has been achieved by means of introducing this methodology of cooperative work supported by VCEs.

3.5. Economic Analysis

This section performs an economic analysis to quantify the cost of outsourcing the required computing capacity to a public cloud provider. Even though in this contribution an on-premises cloud belonging to our university has been employed, ODISEA can provision the same computational resources from public cloud providers. Therefore, these techniques can be extrapolated and applied by professors that do not have direct access to a cloud platform in their institutions. In particular, for this study, we will choose AWS, the current market-share leader in public Clouds. AWS provides computing and storage capacity on a pay-by-the-hour basis without requiring upfront investments. This way, the instructor can provide students with the computing, storage and network capacity required to perform the practice lessons with a 24x7 availability and regardless of the computational capacity offered by the educational institution. By joining the AWS Educate program[3], instructors can take advantage of these resources for their students at no cost. AutoCAD and Microsoft Office cannot be run at the moment on AWS due to licensing restrictions but other open-source alternatives exist such as BRL-CAD, LibreCAD, OpenSCAD , FreeCAD and Open Office. The analyses of the memory consumption of the software required for students to perform the practical lessons reveals that used memory grows linearly with the number of students remotely connected to a single machine via Remote Desktop and using the software (AutoCAD) starting with 2,23 GB for 1 student up to 9,1 GB for 18 simultaneous students on a single machine, as shown on Figure 7.).

[3] AWS Educate. https://aws.amazon.com/es/education/awseducate/

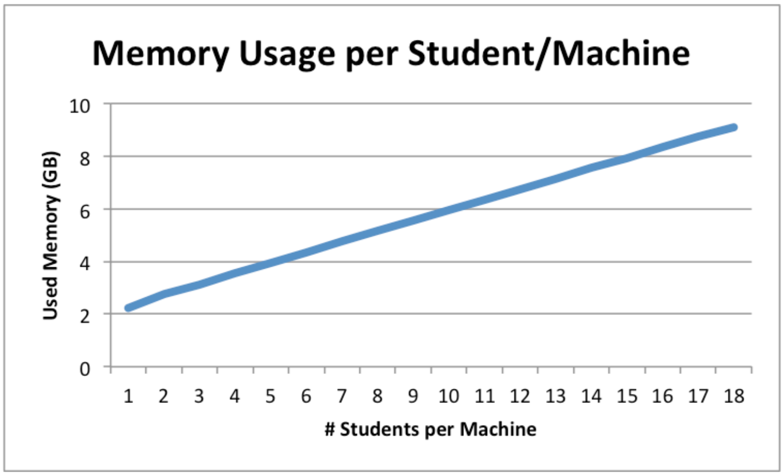

Figure 7. Memory requirements to carry out the lab sessions per each student connected to a single machine via Remote Desktop.

For the study, we identify different scenarios: a) A VCE is created and shared by three different teams (scenario 1). This is the scenario employed in the case study; b) A VCE is created for each team (scenario 2).

Since groups are composed by an average of 5 members (and up to 6 members maximum), the amount of memory for each VCE should be approximately 4 GB of RAM. This allows memory enough for 5 simultaneous students connected to the same VCE. In AWS, the Elastic Cloud Computing (EC2) service allows to deploy Virtual Machines (VMs) that feature a set of computational resources, in terms of computing (virtual CPUs - vCPUs) and memory capacity (amount of RAM). For this, each *instance type* supports a different set of computational resources and the user has to choose from the multiple instance types according to the requirements. For this case, the *t2.medium* instance type (2 vCPUs, 4 GiB) is powerful enough to satisfy the requirements for scenario 2 (approx. 5 simultaneous students) and the *t2.large* instance type (2 vCPUs, 8 GiB) is suitable for scenario 1 (approx. 15 simultaneous students). Remember that not all students may be connected at the same time to a single VCE since they are made available on a 24x7 basis and groups can decide their own schedule. Therefore, we are assuming worst-case scenarios. For this, Table 6 summarises the information and the cost of deploying the VCEs on the UE Ireland region on AWS.

Table 6. Summary of the scenarios and involved cost to support the VCEs on AWS.

Scenario	Max. simultaneous students	Instance type	Cost / hour / VCE ($)	Number of VCEs	Cost / day ($)
Single VCE for team	5	t2.medium	$0.056	28	37,6
Shared VCE for 3 teams	15	t2.large	$0.112	10	26,88

Notice that these costs can be further reduced by removing the 24x7 access assumption and providing, for example, access only 12 hours a day so that students plan their access from 08:00 to 20:00. This would automatically half the costs. The price of a high-end workstation with 16 GB of RAM is in the order of 1.100 $ (e.g. a Dell XPS 8900 workstation costs 999 € in dell.es as consulted on January 2017). Therefore, providing a physical laboratory for a large number of students represents a significant amount of money, unless a usual time-sharing method is applied. In particular, a physical laboratory to simultaneously support the 144 students would require at least 143.856 € for the investment in hardware, without considering the cost for the room, cabling, networking, IT staff, hardware maintenance, etc. In addition, the benefits of using the cloud is both the ability to scale beyond the limits of a physical laboratory by deploying and terminating VCEs as required. We truly believe that the benefits introduced by cloud computing techniques will reshape the way computational resources are currently employed in higher education, with the adoption of on-premises and public clouds to seamlessly support the disparate computational requirements coming from different the subjects in the myriad of degrees offered by educational institutions.

4. Conclusions

This paper has described the application of the ODISEA platform to deploy Virtualized Computing Environments on an on-premises cloud platform to support a PBL activity that it is performed by working groups through a subject (INEL) in the area of Architecture. The system provided students with the computational resources, software and educational material required to perform all staged defined at the PBL activity in a centralized manner and easily accessible anywhere and anytime.

The use of VCE customized to perform a PBL in working groups has produced a positive impact on the final marks, incrementing the average 1.4 points and accumulating the largest number of students in the range of [9,10]. Also, the number of voluntary deliverables has increased, indicating that the motivation has been increased in the pilot groups. In both cases, we can conclude that this positive difference is statistically significant. It is important to highlight the reuse of VCEs in different PBL activities of other subjects. Notice that we can reuse the part of the recipe that define the shared folders and include only the new software and hardware required.

The same VCE can be deployed in public or on-premises clouds depending on the amount of scalability required. Being able to use both on-premises and public clouds, ODISEA enables educational enters to introduce cost saving strategies by outsourcing computational resources on public cloud platforms.

The results of the experience indicate that students feel very positive and satisfied with the experience. In particular, the ability to access the required resources, specially licensed applications, off-campus enabled them to better manage their own schedules. Also, using shared folders between students and professors to track the progress of the projects has been an invaluable tool that has fostered interrelation and cooperative work.

Finally, the ODISEA platform can be an ideal complement for blended learning experiences and MOOCs that require remote labs to be easily accessible by students in order to dynamically deploy customized virtual infrastructures on Cloud platforms.

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