Assessment of Cloud-based Computational Environments for Higher Education

J. Damian Segrelles and Germán Moltó
Instituto de Instrumentación para Imagen Molecular (I3M)
Centro mixto CSIC - Universitat Politècnica de València - CIEMAT,
Valencia, España.
Email: dquilis@dsic.upv.es; gmolto@dsic.upv.es

***Abstract*—Education in Engineering requires bringing the students to scenarios as close to reality as possible. Indeed, the new technologies have fostered the development of a wide spectrum of Computational Environments (CE), such as simulators, virtual laboratories or specific software tools. These environments typically share the same Physical Hardware Resources (PHRs) (e.g. laboratories of PCs) for different subjects on which the CEs are deployed. It is especially important to properly and efficiently manage the rationalization of these PHRs so that the level of service, scalability and versatility is maintained without requiring additional investments in new hardware. The innovation in this work consists on introducing Virtualized CEs (VCEs) based on Cloud Computing by means of the open-source ODISEA platform. The benefits have been assesed and evaluated through 12 educational activities carried out in 8 subjects across 4 degrees at the Universitat Politècnica de València (UPV), in Spain. The results assessed in the paper demonstrate that ODISEA provides economical benefits for the educational institutions. Also, the platform provides the students with ubiquitous and highly available access to VCEs. In addition, this approach fosters BYOD (Bring Your Own Device) where students use their own computers to access the remote labs provided by the VCEs.**

I. Introduction

The European Higher Education Area (EHEA)[1] requires the students to gain experience with specific tools to solve real problems. For this aim, the advances in Information and Communication Technologies (ICTs) have fostered the development of a wide spectrum of Computational Environments (CEs) that are executed on underlying Physical Hardware Resources (PHRs) to support Educational Activities (EAs). These CEs are presented as simulators[1][2][3] virtual laboratories [4][5] and specific software tools [6][7].

This contribution focuses on EAs that require CEs composed by a set machines involving certain hardware, software and complex configuration requirements. For example, a subject on an advanced Computer Science topic such as distributed systems may require that students access a set of machines configured as a Hadoop cluster with support for the Java programming language and some pre-staged datasets.

In general, CEs provide significant benefits for educational centres and students, though their deployment is not free from difficulties and challenges, which are summarised below.

From the point of view of the educational institutions, there are two basic aims: to improve the learning outcome of students and to cut down the budget allocated to the acquisition and maintenance of their resources while maintaining an appropriate quality of service. In this sense, the acquisition and use of CEs improves the teaching-learning process as demonstrated in different studies in Higher Education [8]. However, their acquisition and maintenance is economically convenient only under certain circumstances because there are challenges that remain unsolved:

(a) **Complex maintenance of the CEs**. Problems might arise due to the wide spectrum of CEs and software tools that may require both complex PHRs configurations and potentially incompatible specific software requirements. Typically, the educational institutions are multi-disciplinary environments with different academic subjects that share the same PHRs (e.g. laboratories of PCs).
(b) **Rationalization of PHRs associated to CEs**. It is specially important to properly and efficiently manage the PHRs of an education center so that the level of service and versatility is maintained without requiring additional investments in hardware, specially in the context of an economic crisis, and to reduce the carbon footprint [9].
(c) **Bring Your Own Device (BYOD) to access the CEs**. When students are allowed to bring their own devices to school, the educational institution is not required to purchase as many laptops. Economics also play an important role to leverage BYOD for interacting with the CEs [10].

From the point of view of students, CEs enable them to interact with real or simulated tools used in their professional environments. However, there are fundamental challenges that need to be addressed:

(a) **Ubiquitious Availability of the CEs**. Students should be provided with ubiquitous and 24/7 access to CEs, which has many pedagogical advantages [11] such as more efficient time-management and the ability to work collaboratively [12] regardless of space and time.
(b) **Bring Your Own Devices (BYOD)**. Students should be allowed to access the CEs using their own devices because there are important advantages such as promoting a greater participation in the classroom [13] and a positive attitude and motivation from students [14] [15].
(c) **Variety of CEs**. Introducing different CEs within an EA enables students to access a wide range of platforms or

[1]Bologna Process - European Higher Education Area: http://www.ehea.info

tools, enriching the variety of the activity.

Our hypothesis is that Cloud Computing is an appropriate technology to overcome the challenges and difficulties described above. Cloud computing [16][17][18] arises as a paradigm to rapidly provision and release configurable resources, mainly computing and storage. A Virtualized CE (VCE) consists of a set of customized Virtual Machines (VMs) running on a Cloud provider, either on-premises or public. These VMs can be customized and configured to deploy VCEs that satisfy the hardware, software and configuration requirements for an educational activity. This enables to dynamically deploy virtual infrastructures on top of a fleet of Virtual Machines (VMs) running on top of PHRs, when using the Infrastructure as a Service (IaaS) Cloud service model. The usage of virtualization [19] enables to increase the usage of hardware and thus reducing the investments on additional hardware. In the case of a public Cloud provider, such as Amazon Web Services (AWS), Microsoft Azure or Google Cloud Platform, a pay-per-use model is employed so that users are charged for the resources consumed in terms of hours or minutes of computing, network traffic, etc. In the case of private or on-premises Clouds, tools such as OpenStack[2] or OpenNebula [20] allow system administrators to deploy Cloud infrastructures on top of the the educational institution PHRs.

In our previous work [21], the ODISEA platform was introduced, validated and assessed by means of 6 EAs carried out through 6 subjects involved in 2 different degrees at the Universitat Politècnica de València (UPV) during the academic course 2013/2014. In this previous work, the validation was addressed only from the point of view of the lecturers, demonstrating: a) The capability to provide elasticity and scalability of the VCEs; b) The capability to reproduce a precise clone of a VCE at a later point in time; c) The capability to share and reuse the VCEs among different EAs; d) The user-friendly interface of the platform to manage the VCEs.

The innovation in this work consists on introducing VCEs based on Cloud Computing in multiple EAs across on-premises and public Clouds by means of the ODISEA open-source platform with the goal of assessing its benefits from the point of view of the educational institution and for the students. This contribution goes far beyond the current trend of using virtualization to ease the configuration and update of the physical labs, which basically represents a benefit for the system administrators. Virtualization itself is not enough to provide the automated deployment and configuration of complex VCEs (involving multiple machines with inter-dependent configuration among them) and that have to be dynamically deployed in minutes and easily disposed of after the educational activity via a high-level Graphical User Interface (GUI) that can be operated by the professors themselves. Therefore, this contribution complements our previous work [21] and, together, represent a practical approach on using Cloud Computing to support educational activities that require CEs.

[2]OpenStack: http://www.openstack.org/

After the introduction, the remainder of the paper is structured as follows. First, section II briefly describes the ODISEA Platform and the phases required to use it. Section III presents the objectives of this paper. Then, section IV describes the platform validation carried out through 12 EAs across 8 subjects. Next, section V presents the assessment and introduces a discussion of the benefits and drawbacks of the proposed platform. Finally, section VI summarises the paper and points to future work.

II. ODISEA Platform

ODISEA, an acronym for *On-demand Deployment of Infrastructures to Support Educational Activities*, is an open-source platform to deploy VCEs both on public and on-premise Clouds, with the precise hardware, software and configuration requirements to perform specific EAs.

A. Architecture

The technical details of ODISEA platform architecture were presented in [21]. Basically, the architecture is composed of three layers (see Figure 1). The Level 1 is a repository of Virtual Machine Images (VMIs) with a pre-installed Operating System. Software requirements can be deployed at runtime via the Ansible tool. However, complex or time-consuming software can be pre-packaged into specific VMIs to speed up the deployment process of the VCE. Level 2 consists of a repository of recipes, which are described with a high level language supported by ODISEA named RADL [22]. Each recipe describes the rules to create a VCE, specifying the VMIs (from Level 1) and the hardware resources required for the VCE, in terms of vCPUs (virtual CPUs), Hard Disk size, network connectivity, etc.) and software resources. The third layer, is composed by a set of Cloud providers, where the VCEs can be provisioned and configured considering the recipes from Level 2. These providers can be on-premise (such as OpenNebula or OpenStack, and even virtualization platforms such as Xen or KVM) or public providers (such as Microsoft Azure, Amazon Web Services, etc.).

B. Using ODISEA

ODISEA is typically used following these three phases:

1) (Phase 1). Firstly, the lecturer analyzes the subjects to identify the CEs (simulators, virtual laboratories or specific software tools) required in the EAs in her course or subject. Information such as the number of students by CEs together with their period of use must be determined. Also, the hardware and software requirements have to be identified.
2) (Phase 2). Secondly, the lecturer creates the descriptions of the VCEs in ODISEA depending on the list of CEs detected at, reusing existing VMIs (Level 1), recipes of VCEs (Level 2) and choosing the cloud provider (Level 3) accessible by the lecturer. Depending on the computer skills of the lecturer, this may require further support from a system administrator. ODISEA uses the GUI provided by the Infrastructure Manager (IM) [23].

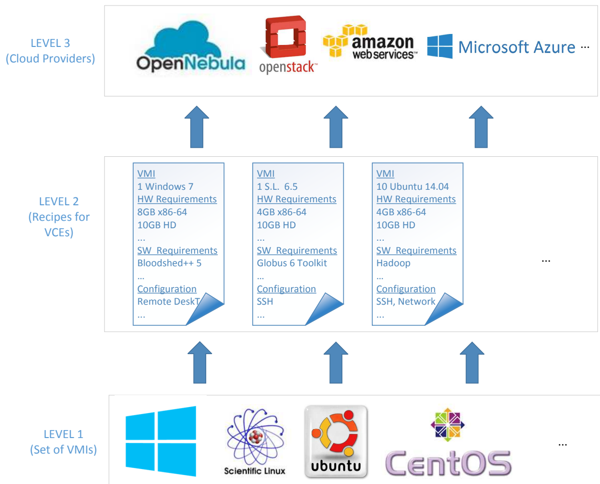

Fig. 1. Levels of the ODISEA Architecture.

Access is currently provided as a web tool [24] where no registration is required to use it. Readers are encouraged to use it and submit feedback.

3) (Phase 3). Finally, the lecturer uses ODISEA to manage the lifecycle of the VCEs by deploying them before the EA start and to terminate them once the EA has finished.

Note that the usage of ODISEA by the lecturers is not restricted to institutions that support a Cloud platform. AWS offer the AWS Educate[3] program where institutions, educators and students can join to obtain credits to access AWS technology. In particular the Amazon EC2 service allows educators to deploy Virtual Machines for free (until consuming the amount of credits obtained). Therefore, we believe that platforms such as ODISEA pave the way for educators to dynamically deploy complex remote labs, accessible anywhere and anytime, to support their educational activities with an unprecedented degree of flexibility when compared to traditional physical laboratories.

III. Objectives

In this work, we extend the assessment of the ODISEA platform initiated in [21], and the main objective is to validate and assess ODISEA from the point of view of the educational institution and students in order to resolve the challenges exposed in section I. This validation has been performed through 12 EAs carried out in 8 subjects involved in 4 different degrees at the Universitat Politècnica de València (UPV) during the academic course 2015/2016.

These are the parameters to evaluate concerning the educational institution:

- The ability to **improve the teaching-learning process**, easing the use of VCEs in the EAs.
- The reduction of the budget of **acquisition** and **maintenance** of PHRs associated to VCEs, simplifying their configuration and update.
- The promotion of **BYOD** in the students, avoiding investments in devices that can be provided by the student (such as laptops).
- The capability of providing an efficient **rationalization** of PHRs, avoiding the upfront investments in additional PHRs.

These are the parameters to evaluate concerning the students:

- The capability to provide **high availability and ubiquitous access** for the VCEs.
- The ability for students to use their own devices in the learning activities, thus **promoting BYOD**.
- The capability to access different VCEs, enabling the students to work with a wide range of platforms and or tools, thus enriching the **variety** of EAs.

IV. Validation

This section describes the validation process to asses the ODISEA platform with respect to the parameters identified in the previous section. First, a brief description of the Cloud platforms used for the validation is provided. Second, the usage of ODISEA within the different EAs is described, following the phases described in section II-B.

A. Cloud Providers

We have used different Cloud platforms from which the hardware resources that support the VCEs are provisioned:

- An on-premises IaaS Cloud platform with a total of 128 cores and 352 GB of RAM managed by OpenNebula 4.2 to provision a large number of VMs.
- The AWS public Cloud, to provision computing, storage and network capacity on a pay-as-you-go basis. Our institution joined the AWS Educate program and, therefore, credits are available to cover the costs of the main AWS services.

B. Analyzing EAs and Identifying CEs (Phase 1).

The ODISEA Platform has been extensively employed in four academic degrees such as the Bachelor's Degree in Industrial Electronics and Automation Engineering (BIEA), the Master's Degree in Parallel and Distributed Computing (MPDC)[4], the Master's Degree in Informatics Engineering (MIE)[5], and an Online Postgraduate Course (OPC) at the Universitat Politècnica de València (UPV). In this phase each subject is analyzed together with the CEs required to carry out the EAs. Table I includes a summary of them though a brief description is provided here:

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

[4] http://www.upv.es/titulaciones/MUCPD

[5] http://muiinf.webs.upv.es

TABLE I
LIST OF SUBJECTS, EDUCATIONAL ACTIVITIES (EAS) SCHEDULED, CES INVOLVED AND THE NUMBER OF STUDENTS PER SUBJECT.

DEGREE	SUBJECT	EAs	ACTIVE	CEs	Nº
BIEA	Computer Science (INF)	E.A.1	16 weeks	-Bloodshed Dev-C++5 (IDE + Compiler)	36
MIE	Medical Informatics (IME)	E.A.2	8 weeks	-DCM4CHEE PACS Server -TUDOR DICOM toolkit + NetBeans IDE	6
	Grid and Cloud Computing Concepts (CCGC)	E.A.3	6 weeks	-Globus Toolkit 6 -Public Key Infrastructure (PKI) based on OpenCA	14
		E.A.4	4 hours		
		E.A.5	4 weeks		
MCPD	Grid Advanced Infrastructures (IAG)	E.A.6	7 weeks	-CLIs of gLiteUI package -OpenLDAP service and Berkeley Database -Public Key Infrastructure (PKI) based on OpenCA	6
		E.A.7	2 weeks		
		E.A.8	4 weeks		
MCPD	Grid Programming Models (MPG)	E.A.6	1 week	-CLIs of gLiteUI package -OpenMP compiler	12
MCPD	Cloud Programming Models (MPC)	E.A.9	7 weeks	-Python user interface to AWS (Boto) and AWS CLI - Hadoop Cluster	15
		E.A.10	4 hours		
MCPD	Cloud Advanced Infrastructures (IAC)	E.A.9	7 weeks	-Python user interface to AWS (Boto) and AWS CLI -Ansible -OpenNebula Testbed	15
		E.A.11	4 hours		
		E.A.12	4 hours		
OPC	Online Course on AWS (CloudAWS)	E.A.9	70 days	-Python user interface to AWS (Boto) and AWS CLI -Ansible	380
		E.A.11	4 hours		

E.A.1. Developing C Programs. The students learn programming skills developing C programs in class using Dev-C++[6] or autonomous tasks using their own computers (Dev-C++ for Windows or Xcode for OS X) as homework.

E.A.2. Developing DICOM applications. The students learn the DICOM protocol for managing medical images and they develop DICOM programs in the classroom and autonomous tasks to transfer and encapsulate medical images using TUDOR DICOM[7] toolkit with the NetBeans IDE[8], and interacting with a DCM4CHEE PACS Server[9].

E.A.3. Developing Grid Applications. The students learn Grid programming skills and develop Grid applications using the Globus Toolkit 6 (GT6)[10] in the classroom or via autonomous tasks.

E.A.4. Developing Grid Secure Applications. The students learns basic concepts about Grid security issues and they create X.509 certificates (just-in-time for the practice lesson) to secure connections during just one practice lesson. A Public Key Infrastructure (PKI) based on OpenCA[11] is used.

E.A.5. Developing a Grid Project. Students are evaluated by developing a grid project. Each student configures and uses a secure grid infrastructure based on GT6 , and develop a complex grid application that use the created infrastructure. For the project a PKI (managed by the lecturer) is required for all students. Also, each student requires a grid infrastructure composed of three machines with GT6.

E.A.6. Developing an Advanced Grid Application. The students learn Grid programming skills. Each student develops advanced grid applications using gLite Command Line Interfaces (CLIs)[12] interacting with the European Grid Infrastructure (EGI)[13] through classroom or homework tasks.

E.A.7. Developing LDAP Services. The students learn basic and advanced concepts about LDAP Services. Each student should configure secure grid information services based on OpenLDAP[14] using the Oracle Berkeley Database as back-end emulating replicated models via classroom tasks. For this, each student need two resources (PCs) with OpenLDAP, a Berkeley DB and a PKI infrastructure to generate certificates.

E.A.8. Developing an Advanced Grid Project. The students are evaluated by developing a Grid project. Each student uses the EGI infrastructure and develops a complex grid application using the gLite CLI.

E.A.9. Architecting with AWS Cloud Services. The students use different services provided by AWS to create architectural designs of applications and deploy them on the AWS Cloud using Boto[15] and the AWS CLI[16]. The activity is performed via classroom and autonomous tasks.

E.A.10. Analysing Big Data with Apache Hadoop. The students create programs based on the MapReduce programming model to extract information from large datasets available in an Apache Hadoop[17] cluster, deployed with 10 nodes, and shared by all the students.

E.A.11. Automatic Configuration of Infrastructures. Each student deploys two VMs via a shell-script, just-in-time for the practice lesson, and use the Ansible tool to practice with the automated configuration of VMs. The activity is performed through classroom tasks.

E.A.12. Provision of VMs from an on-premises Cloud. The students use the functionality of OpenNebula to deploy

[6]Dev-C++.http://www.bloodshed.net/devcpp.html
[7]TUDOR DICOM tools. http://www.santec.lu/project/dicom
[8]NetBeans IDE. https://netbeans.org/
[9]DCM4CHEE PACS Server. http://www.dcm4che.org/
[10]Globus Toolkit 6. http://toolkit.globus.org/toolkit/docs/latest-stable/
[11]Open CA. http://www.openca.org/
[12]gLite. http://grid-deployment.web.cern.ch/grid-deployment/glite-web/
[13]EGI. http://www.egi.eu/
[14]OpenLDAP project. http://http://www.openldap.org
[15]http://boto.readthedocs.org/en/latest/
[16]http://aws.amazon.com/es/cli/
[17]http://hadoop.apache.org

```
network public (inbound = 'yes')
system iac (
  cpu.arch='x86_64' and
  cpu.count>=1 and
  memory.size>=1024m and
  net_interfaces.count = 1 and
  net_interface.0.connection = 'public' and
  disk.0.os.name='linux' and
  disk.0.os.flavour='ubuntu' and
  disk.0.os.version>='14.04'
)
configure iac (
@begin
- vars:
 - pw_00: M3Je2TpgZ3n
 tasks:
 - user: name=alucloud00 password=$pw_00
 - get_url: url=<sdr_url>/${item} dest=/tmp/${item}
   with_items:
    - iaccourse_1.0_all.deb
 - command: dpkg -i /tmp/${item}
   with_items:
    - iaccourse_1.0_all.deb
 - apt: pkg=mysql-client-5.5 state=installed
@end
)
deploy iac 1
```

Fig. 2. Part of the RADL document to deploy the remote lab for the IAC subject.

VMs and dynamically allocate storage capacity from an OpenNebula deployment during the classroom.

C. Implementing the VCEs in ODISEA (Phase 2).

The second phase consists of implementing the VCEs to support the different EAs based on the CEs identified at phase 1. For each CE (identified in Table I) a VCE is implemented and we provide details about the first two levels of ODISEA (see Table II), which addresses the VMIs and the recipes. All the hardware, software and configuration requirements are expressed by means of a recipe for each VCE created. As an example, Figure 2 includes an excerpt of the recipe to deploy the remote lab (VCE) for the IAC subject, where the hardware, software and configuration requirements (user accounts, download educational material, install applications, etc.) are expressed in RADL.

D. Integration and use of the VCEs in the EAs (Phase 3).

In the third phase the VCEs were integrated in the EAs. The results of this phase are shown in Table III which shows the EAs where the VCEs have been used and the features provided by the Level 3 of the ODISEA platform.

To perform **E.A.1** seven PRG VCEs (one per student) where deployed, accessed by a user account and used for implementing the C programs. The students connect via Remote Desktop and, therefore, use the same framework (Dev-C++) regardless of their client device platform (OS X, GNU/Linux, etc).

To perform **E.A.2** one PACS VCEs was created and shared by all students together with six DICOM VCEs (one per student) using a personal user account for implementing the DICOM applications. The students connect to the VCE DICOM via Remote Desktop or a web browser to interact with the VCE PACS for testing the results of the DICOM applications created.

To perform **E.A.3** and **E.A.4** 14 GT6 VCE (one per student) were deployed for implementing the Grid applications. Also, one PKI VCE was created for four hours to create X.509 certificates.

To perform **E.A.5** three GT6 VCE per student (42 in total) were created for developing the Grid project using their own resources. Also, it was created one VCE PKI shared by all students.

To perform **E.A.6** in IAG and MPG a single gLiteUI VCE was created and shared by all students by means of different user accounts. It was employed to create advanced Grid applications which allow access to EGI.

To perform **E.A.7** two LDAP VCEs per student (12 in total) were created for implementing the secure LDAP services with different replication models. Also, one PKI VCE was created to generate the X.509 certificates required to implement secure services.

To perform **E.A.8** one gLiteUI VCE was deployed, shared by all students by means of user accounts creating advanced complex Grid application which allow to access to EGI. This activity shares VCE with E.A.6.

To perform **E.A.9** in MPC, IAC and CursoCloudAWS a single AWS VCE was created shared by all the students with different user accounts. They use the VCE to create architectural designs of applications and deploy them on the AWS Cloud.

To perform **E.A.10** a shared Hadoop Cluster VCE with multiple user accounts is used to create programs based on the MapReduce programming model. The VCE is deployed on the on-premises Cloud and on the AWS public Cloud to carry out different performance analysis.

To perform **E.A.11** in IAC and CursoCloudAWS two Ansible VCEs per student (30 and 760) are created on-demand by each student using pre-configured scripts. The use it to learn the fundamentals of the Ansible tool.

To perform **E.A.12** only one OpenNebula (ONE) VCE was created shared by the students via multiple user accounts. They use it to deploy VMs on an existing Cloud deployment.

In all EAs when an activity finished the VCEs involved were terminated and the resources associated to VMs were released.

V. Assessment and Discussion

This section evaluates the parameters and capabilities of ODISEA that have been described as objectives in section III. The assessment has been done through the different EAs that have been validated at section IV.

A. The capability of improving teaching-learning.

ODISEA is a platform to ease the deployment of VCEs in EAs. In this sense, the capability of improving the teaching-learning process due to the use of VCEs is demonstrated in different studies, for example in fields such as mechanics [25] or electrical engineering [26] and other more generic studies in Higher Education such as [8].

TABLE II

VCEs IMPLEMENTED AT ODISEA. IT IS SHOWN THE FEATURES OF LEVEL 1 AND LEVEL 2 OF THE PLATFORM.

VCE	**LEVEL1**	**LEVEL 2**			
	O.S	VMs	Hardware	Software	Configuration
PRG	Windows 7 Professional	1	8GB,x86-64 70GB HD	-Dev-C++5	-User accounts and privileges to develop C programs. -User accounts to access via Microsoft Remote Desktop.
PACS	Windows 7 Professional	1	8GB,x86-64 50GB HD	-DCM4CHEE Server	-Accessible via web browser with user and password.
DICOM	Windows 7 Professional	1	8GB,x86-64 50GB HD	-TUDOR toolkit -NetBeans 8.1	-Users enabled to access via Microsoft Remote DeskTop.
GT6	Scientific Linux 6.7	1	4GB,x86-64 20GB HD	-Globus Toolkit 6	-User accounts with privileges to develop grid applications. -User accounts to access via SSH with a password.
GLite	Scientific Linux 6.7	1	2GB,x86-64 10GB HD	-gLite User Interface -OpenMP compiler	-gLite CLIs and X.509 cert. to connect to EGI infrastructure. -User accounts to access via SSH with a password.
PKI	Ubuntu 13	2	1GB,x86-64 10GB HD	-OpenCA 1.4	-Two VMs configure a RA and a CA. -Accessible via Web browser with a user and password.
LDAP	Scientific Linux 6.7	2	4GB,x86-64 10GB HD	-Berkeley DB 6 -OpenLDAP 2.4	-An OpenLDAP (VM) and BerkeleyDB (VM) admin user. -User accounts to access via SSH with a password.
AWS	Ubuntu 14.04	1	1GB,x86-64 10GB HD	-Python and Boto -AWS CLI	-Multiple users to access the services. -User accounts to access via SSH with a password.
HADOOP	Ubuntu 14.04	10	2GB,x86-64 10GB HD	-Hadoop	-Multiple users and different pre-staged large datasets. -Accessible via web browser with a user and password. -User accounts to access via SSH with a password.
Ansible	Ubuntu 14.04	2	1GB,x86-64 10GB HD	-Ansible	-Set of VMs to be accesses to via SSH without password.
ONE	Ubuntu 14.04	2	1GB,x86-64 10GB HD	-OpenNebula	-Multiple users to access the OpenNebula testbed. -User acccounts to access via SSH with a password.

TABLE III

VCEs EMPLOYED IN THE DIFFERENT EAs.

SUBJECT	**E.A.**	**VCE**	**# of VCEs**	**ACCESS**	**# of VMs**	**AVAILABILITY**	**CLOUD PROVIDER (LEVEL 3)**
INF	E.A.1	PRG	7	Remote Desktop	7	16 weeks 24x7	On-premises
IME	E.A.2	PACS DICOM	1 6	Web browser Remote Desktop	1 6	8 weeks 24x7	On-premises
CCGC	E.A.3	GT6	14	SSH client	14	6 Weeks 24x7	On-premises
	E.A.4	PKI	1	Web browser	2	4 Hours	
	E.A.5	GT6 PKI	42 1	SSH client Web browser	42 2	4 Weeks 24x7 4 Weeks 24x7	
IAG	E.A.6	gLiteUI	1	SSH client	1	7 weeks 24x7	On-premises
	E.A.7	LDAP PKI	12 1	SSH client Web browser	24 2	2 weeks 24x7	
	E.A.8	gLiteUI	1	SSH client	1	4 weeks 24x7	
MPG	E.A.6	gLiteUI	1	SSH client	1	1 weeks 24x7	On-premises
MPC	E.A.9	AWS	1	SSH client	1	7 weeks 24x7	AWS Cloud Provider
	E.A.10	HADOOP	1	SSH client	10	4 hours 24x7	AWS Cloud Provider / On-premises
IAC	E.A.9	AWS	1	SSH client	1	7 weeks 24x7	AWS Cloud Provider
	E.A.11	Ansible	30	SSH client	30	4 hours	
CloudAWS	E.A.9	AWS	1	SSH client	1	7 weeks 24x7	AWS Cloud Provider
	E.A.11	Ansible	760	SSH client	760	4 hours 24x7	
	E.A.12	ONE	1	SSH client / Ansible	2	4 hours 24x7	

B. Reduce of the budget of acquisition of PHRs associated to VCEs

ODISEA is able to deploy the VMs that support the VCEs on on-premises cloud and public clouds. This allows reducing the budget of acquisition of PHRs associated to VCEs. The E.A.11 is a clear example of this issue. E.A.11. required many simultaneous Ansible VCEs both for the IAC subject and the online course. In this situation, the educational centers may not have available all the required PHRs to execute the VCEs and the on-premises cloud resources could be insufficient. That is the main reason to use a public cloud, where additional resources can be provisioned on a pay-by-the-hour model. This way, it is not necessary to invest in new PHRs to support the activity, reducing the budget of acquisition of PHRs associated to VCEs as we can see at table IV. This table compares the cost of acquisition of a certain number of machines so that students can perform the practical lessons. These will be noted as on-premises physical machines and their price has been obtained from dell.com choosing the average price of the set of computers for the desktop category, which results in 426

€ (including the monitor, 4 GB of RAM, 1 TB of disk). For the virtual machines on AWS we selected the $m1.small$ instance type (1.7 GB of RAM, 160 GB of disk), which is powerful enough to perform the practice lessons. Considering the pay-per-use model of AWS, we estimate that 4 hours are required to perform the practice lesson that involves Ansible. Costs for AWS have been estimated using the AWS Simple Monthly Calculator[18]. Dollar-euro ratio was 1 $ = 0.79815 € at the time the study was performed.

You can derive from the table that it would take more than 16 months of 24/7 running instances to match the cost of the on-premises physical machines. Notice that the table does not include the cost of maintenance of hardware, electricity and housing of the equipment. If we restrict the comparison to the specific duration of the practical lesson (4 hours) you can estimate from the table that the activity could be performed more than 3.040 times before matching the cost of the on-premises physical machines. Therefore there is a clear cost reduction when outsourcing the computational resources for the E.As to the Cloud.

C. Reduce the maintenance budget of PHRs for VCEs.

All implemented VCEs in ODISEA require complex PHRs configurations and the specific software requirements can be potentially incompatible (see Table II) between them. In the validation process, 11 VCEs have been implemented and used in multi-disciplinary environments with different academic subjects, sharing the same PHRs available in the on-premises cloud. ODISEA has allowed provisioning and configuring PHRs in an affordable and practical way, avoiding the technical overhead of switching among configurations and the intricacies of the configuration and customisation of the infrastructures, reducing the budget of maintenance of the resources associated to VCEs.

D. The ability for students to use their own devices in the learning activities, thus promoting BYOD.

All implemented VCEs in the ODISEA platform allow SSH connections, Remote Desktop or web access to be accessed by the students. This leverages BYOD among them because they can use their own devices (laptops or personal computers) using different platforms (OS X, Windows, GNU/Linux) for performing the EAs since the PHRs capabilities (hardware and software requirements) are provided by the cloud. This feature has allowed students to perform the EAs related with online course using their own devices (laptops or personal computers). In addition, in the E.A.1 the students have connected to the VCEs using a Remote Desktop and only seven VMs have been deployed on the on-premises cloud. In this EA, there are 36 students and 97% have used their own devices (laptops) for connecting to the VCES. In previous scenarios, it was necessary one computer per student, using physical laboratories to perform the activities. Nowadays, using ODISEA, only seven VCEs (7 VM with 5-6 users per VM) have been necessary.

[18]Available at http://calculator.s3.amazonaws.com/index.html

E. Capability to ease the configuration and update process of the VCEs.

The ODISEA architecture (see section II) allows defining three implementation levels for each VCE. The lowest level (Level 1) corresponds to the basic Virtual Machine Images (VMIs). On top of these VMIs, the second level describes the hardware (HW), software (SW) requirements and configuration for each VM throuht a high-level language. The third level define the clud provider. The three levels enable ODISEA to ease the configuration and update process of the VCEs. For example, the group composed of PRG, PACS and DICOM VCEs or the group of GT6, gLiteUI and LDAP VCEs or the group of VCEs composed of AWS, HADOOP, Ansible and ONE are used in different EAs activities (see Table III)) and all VCEs of each group use the same Operating System (OS). The first group uses Windows 7 Professional, the second group Scientific Linux 6.7 and the third group uses Ubuntu 14.04. Within ODISEA, just one VMI (first level) with the basic OS has been created. In this way, when a VM is instantiated to support a given VCE, ODISEA deploys the HW requirements and configures the SW requirements. That is why the configuration and update process is simplified, if a new OS package versions appear it is just necessary to update the VMI. New versions of software are updated in the base VMI and applied to VCEs when new instances are deployed.

F. Provide an efficient rationalization of PHRs.

ODISEA has been used to dynamically deploy the VCEs required for the EAs. Once finished the EAs, the VCEs are terminated because there is no need to maintain the VCEs up and running and the underlying PHRs can be employed to support other EAs for other VCEs. In the validation process, eight VCEs were implemented, which shared the same PHRs belonging to the on-premises cloud. Note that in-campus software licenses can still be valid for VCEs deployed on on-premises Clouds within the educational institution.

G. Provide high availability for the VCEs and ubiquitous access for the students.

In the INF subject a questionnaire was employed with regard to this issue. The first item of the questionnaire questioned the students whether they had connected to the VCEs from other places different to the specific laboratories of the subject (at home, library, etc.) and if the resources had always been available. 100% of the students had also worked outside of the university (for example at home) and claim to have had always available the VCEs.

In the case of CursoCloudAWS, the VCEs deployed are configured with special monitoring alarms via the Amazon CloudWatch service that enables to deliver instant notifications to the instructor in case the remote laboratory is either overloaded (CPU $>$ 70% for more than 10 minutes) or inaccessible. This enables to introduce corrective measures so that high availability for students is guaranteed. Also, multiple instances (clones) can be deployed to ensure availability.

TABLE IV
COST COMPARISON OF A CERTAIN NUMBER OF PHYSICAL MACHINES VS THE USAGE OF VIRTUAL MACHINES ON AWS FOR A SPECIFIC ACTIVITY LESSON THAT LASTS 4 HOURS.

#Machines	Cost of On-premises Physical Machines (€)	Cost of Virtual Machines on AWS (just 4 hours) (€)	Monthly Cost of Virtual Machines on AWS (24 hours / day) (€)
10	4.260	1.4	257
20	8.520	2.9	514
50	21.300	7.2	1.284
100	42.600	14.4	2.570

H. The capability to introduce different VCEs, enabling to the students to access a wide range of platforms or tools.

Three EAs (E.A.2, E.A.5 and E.A.7) have used different VCEs (see Table III) that have also been used in other EAs. Also, all subjects (see Table III) except INF and MPG use more than one VCE during the course. In particular the subjects IME, CCGC, IAC and MPC use two different VCEs in their EAs and the subjects IAG and CursoCloudAWS uses three. This variety of VCEs in the subjects and their EAs is because ODISEA allows to reuse the recipes of the VCEs in a easy way and deploy them in a user-friendly manner.

VI. CONCLUSION AND FUTURE WORK

The ODISEA platform has been validated and evaluated thought of different EAs belonging to 8 subjects of four different knowledge areas which are Bachelor's Degree in Industrial Electronics and Automation Engineering (BIEA), the Master's Degree in Parallel and Distributed Computing (MPDC), the Master's Degree in Informatics Engineering (MIE), and an Online Postgraduate Course (OPC). Furthermore, the total number of VCEs identified and implemented in the ODISEA platform for supporting the EAs has been 11, in which each VCE has different features (hardware and software requirements, availability, number of VMs, connection type, different clouds where the VMs are deployed, etc.). For this, we can conclude that the ODISEA platform is flexible to support the common VCEs needed in a wide variety of EAs, and the methods and procedures described in this paper can definitely be applied to other similar scenarios.

It is important to highlight the reuse of VCEs among different EAs and also among subjects. Notice that sharing can occur at two levels: First, sharing the VCE description (its recipe) where different virtual infrastructures are really deployed. Second, the very same virtual infrastructure can be shared across subjects, where different user accounts are employed for the students of different subjects. Third, the same VCE can be deployed in public or on-premises cloud depending on the 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 Cloud platforms and fostering BYOD. In addition, this platform is ideal for online courses and MOOCs, where the ability to scale (increase) the virtual infrastructures enables to seamlessly adapt to a dynamic number of students.

Future works include using the platform in more EAs within new fields. We also plan to better customise the virtual infrastructures to leverage work group and, this way, to focus on these transversal competencies so required for our students.

ACKNOWLEDGMENT

The authors wish to thank the financial support received from Vicerrectorado de Estudios, Calidad y Acreditación of the Universitat Politècnica de València (UPV) to develop the PIME project "Análisis y Evaluación de Impacto del Cloud Computing en la Gestión de Entornos Virtuales Computacionales en la Enseñanza", with reference A014. GM would like to thank Amazon for the AWS Educate program and the "Escola Tècnica Superior d'Enginyeria Informàtica (ETSINF) de la Universitat Politècnica de València" for the financial support to present this contribution. The authors would also like to thank the Spanish "Ministerio de Economía y Competitividad" for the project TIN2013-44390-R.

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