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# Cloud computing and education: A state-of-the-art survey

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A B S T R A C T

This paper surveys the state of the art on the use and research of cloud computing in education following a systematic methodology. After a comprehensive search of the scientific literature, 112 works were selected for the review. The survey identifies and analyzes the advantages and risks that the use of cloud computing may have for the main stakeholders in education, which can be useful to identify the scenarios in which the use of cloud computing in an educational context may have significant advantages. Furthermore, the survey categorizes and discusses the main technical and domain-specific research challenges, thus facilitating researchers the task of finding relevant issues, in which they can focus their efforts.



## 1. Introduction

Cloud computing is a distributed computing paradigm that enables access to virtualized resources including computers, networks, storage, development platforms or applications (Mell & Grance, 2009). These resources can be unilaterally requested, provisioned and configured by the user with a minimal interaction with the cloud provider. Furthermore, resources can be rapidly scaled up and down to meet the user's needs, thus creating the illusion of infinite resources available at any time. Resource utilization can be measured in the cloud to be controlled and, sometimes, to charge customers in a pay-per-use basis.

With the support of important industry stakeholders like Google, Amazon or Microsoft, cloud computing is being widely adopted in different domains. Cloud services such as Google Mail[1] or Dropbox[2] have become everyday tools for millions of people. Many companies currently use cloud-based applications such as Salesforce[3] and small and big businesses are embracing virtual infrastructures offered, for instance, by Amazon Web Services (AWS)[4] or Microsoft Azure[5] (Marston, Li, Bandyopadhyay, Zhang, & Ghalsasi, 2011). Among governments, initiatives such as the Federal Cloud Computing Initiative,[6] promote the use of cloud computing, and other organizations, like NASA,[7] are using cloud infrastructures for research, as well.

In the Technology-Enhanced Learning (TEL) domain, the use of cloud-based technologies has also been identified as a key trend (Johnson, Adams, & Cummins, 2012) that enables access to online services anywhere and promises scalability, enhanced availability and cost savings (McDonald, Breslin, & MacDonald, 2010). These affordances are brought about by using cloud computing in contrast to conventional

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1 http://www.gmail.com.
2 http://www.dropbox.com.
3 http://www.salesforce.com.
4 http://aws.amazon.com.
5 http://www.windowsazure.com.
6 http://info.apps.gov/node/2.
7 http://nebula.nasa.gov.

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0360-1315/

computational infrastructure, where both hardware and software are owned and kept by organizations at their premises, maintained, and often developed by their own technical staff.

In education, cloud computing caters for desirable properties to provide e-learning services, especially in scenarios where these services are computer-intensive (virtual worlds, simulations, video streaming, etc.), or are offered in a high-scale way, as in Massive Open Online Courses (MOOCs). The cloud can provide students and teachers with tools to deploy computing resources on-demand for lectures and labs according to their learning needs. For instance, teachers can create virtual computers (commonly named Virtual Machines or VMs) on demand with pre-installed software to deploy computing laboratories rapidly (Chine, 2010). Some educational institutions are already using cloud computing to outsource email services, to offer collaboration tools and data storage for students and to host institutional Virtual Learning Environments (VLEs) (Sclater, 2010a). Other affordances of cloud computing may yield new learning scenarios where ubiquity, advanced online tools and collaboration come together to create innovative opportunities for education. On the other hand, cloud computing brings new risks when compared to the conventional IT model such as security, performance, or interoperability that now have to be considered.

The adoption of cloud computing in education has come hand in hand with an important research effort. There are a great number of scientific contributions that address the topic from different perspectives trying to harness cloud computing services for education. A systematic review of these heterogeneous contributions that assesses the advantages and limitations of the use of cloud computing in education and that provides a coherent picture of the current research challenges in this domain can be of great interest for educational practitioners and institutions in order to identify opportunities to use the cloud in their own context. In addition, such a review can also be very useful for researchers to identify relevant issues and challenges in which they can focus their efforts. These challenges can be either technical issues (i.e., how to improve the cloud technology itself to meet domain-specific needs) or domain-specific opportunities (i.e., how to leverage cloud computing services for pedagogical uses).

A first attempt to carry out such a review was made by Fasihuddin, Skinner, and Athauda (2012). However, it did not follow a systematic methodology to try to ensure the comprehesiveness of the review. Furthermore, it analyzes the advantages and research challenges of the use of cloud computing in education at a shallow level. In addition, the risks of the adoption of cloud computing in education are not identified. It is noteworthy that other studies have been published reviewing the usage of cloud computing in relevant application areas, such as health care (AbuKhousa, Mohamed, & Al-Jaroodi, 2012), governance (Smitha, Thomas, & Chitharanjan, 2012), or commerce (Motahari-Nezhad, Stephenson, & Singhal, 2009).

This paper presents a review of the existing literature on the use of cloud in education following the methodology proposed by Kitchenham and Charters (2007), which has already been used in similar works in other research fields. The review identifies and analyzes the main advantages and limitations of the use of cloud computing in education as well as the current research challenges in this field. Furthermore, it illustrates these issues with relevant learning scenarios found across the literature.

This paper is thus structured as follows. Section 2 provides some background information on cloud computing, characteristics, services and deployment models. Section 3 explains the methodology followed to carry out this review. The main benefits and affordances of cloud computing for education are detailed in Section 4, as well as its risks in Section 5. The main research challenges are identified in Section 6. Finally, discussion and the main conclusions are laid out in Section 7.

## 2. Background on cloud computing

The cloud computing paradigm offers a pool of virtual resources (hardware, development platforms or services) available over the network. These computing capabilities can be provisioned and released to scale rapidly according to demand (Vaquero, Rodero-Merino, Cáceres, & Lindner, 2008).

Cloud computing services are typically categorized into three main types (Mell & Grance, 2009; Zhang, Cheng, & Boutaba, 2010): *Infrastructure as a Service* (IaaS), *Platform as a Service* (PaaS), and *Software as a Service* (SaaS). At the lowest level of abstraction, IaaS is found which provides the consumer with processing, storage, networking, and other computing resources on-demand, for instance, under the abstraction of a Virtual Machine. Examples of IaaS are Amazon EC2[8] and Google Compute Engine,[9] which provide VMs on demand. Eucalyptus[10] and OpenStack[11] are both examples of open source middleware that organizations can use to build their own IaaS. The base software that enables the creation of VMs (i.e., virtualization) is called hypervisor, of which some of the most widely used are Xen,[12] VMWare,[13] and Hyper-V.[14] Hypervisors create different instances of VMs in the native computer which share the actual resources of the host machine and can be dynamically scaled and terminated when they are no longer needed (Buyya, Yeo, Venugopal, Broberg, & Brandic, 2009). Virtualization affords better resource utilization (important for the provider), but also implies computational overheads that decrease performance (important for the service consumer), as reported for example by Wang and Ng (2010). Nevertheless, improvements in software and hardware are bringing performance of virtualized servers closer to native computation (McDougall & Anderson, 2010).

The following level, PaaS, is usually built upon IaaS and allows the user to deploy onto the cloud infrastructure applications created using programming and runtime environments supported by the provider. Software developers and IT staff, but also non-technical users, employ resources at this level. At this layer, Google App Engine (GAE)[15] and Microsoft Windows Azure provide programming and deployment frameworks.

[8] http://aws.amazon.com/ec2/.
[9] https://cloud.google.com/products/compute-engine/.
[10] http://www.eucalyptus.com.
[11] http://www.openstack.org.
[12] http://www.xenproject.org.
[13] http://www.vmware.com.
[14] http://www.microsoft.com/OEM/en/products/servers/Pages/hyper_v_server.aspx.
[15] https://appengine.google.com.