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Cost Estimation of Blended Learning Course Delivery Through Public Cloud

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Abstract: There are a lot of educational institutions that own blended learning platforms, and even more that don't. The era of cloud computing offers a possibility for those who don't own such platforms to utilize public cloud resources for courses delivery. The goal of this paper is design and cost estimation of flexible blended learning platform suitable for cloud implementation. In this paper we present technical requirements and create a mathematical model which allows one to estimate the cost of course delivery through public cloud. As a basis for the cost estimation, a model of blended learning course and a platform that supports the model will be proposed. The platform will be based on open source software, and it will be designed to be suitable and simple for cloud implementation. The proposed blended learning model will be applied and the platform will be implemented on the public cloud on the example of computer networking course. In order to estimate the cost of public cloud hosting, a stress test will be performed varying both virtual hardware and the number of students. Three different virtual hardware configurations will be evaluated with up to 400 students. The analysis of the stress test results will be given, along with the recommendations regarding the virtual hardware in the respect to the audience. The cost function in the respect to the number of enroled students will be given, too. It will be shown that the proposed course delivery model is low-cost, while it is based on the state of the art learning tools. Moreover, the students' achievements will be discussed in the example of two different cohorts of students.

Key Words: Blended learning, learning platform, virtual classroom, cloud applications.

Category: L.3, K.3.1, L.2.5, L.0.0

1 Introduction

1.1 Background and context

Development of technology in the last couple of decades has inspired a wide range of new learning models and environments, which are supported with a large number of tools and applications that tend to improve students' learning curve. The tools vary from dedicated tools that target very specific topics such as computer architectures [Patti et al., 2012, Prasad et al., 2016, Vojinović et al., 2004] or data structures and algorithms [Deperlioglu and Kose, 2013], to the large scale social networks, such as Facebook and Twiter, used as platforms for learning resources delivery [Bicen and Uzunboylu, 2013, Dhir et al., 2013].

In recent years blended learning is gaining a lot of attention due to the growing demand for distance learning and life-long leaning [Moskal et al., 2013, Moss and Smith, 2010, Cortizo et al., 2010, López-Pérez et al., 2011]. The popularity emerges from the fact that it combines online digital media with traditional classroom methods, elevating the learning experience. Blended learning, if well planned and established, exerts good sides of both traditional and online learning. In a nutshell, it is a shift from teaching to learning that requires the presence of both a teacher and a student, where the student has control to a certain extent over time, place, and path [López-Pérez et al., 2011, Nunan et al., 2000].

Introduction of blended learning in an institution is not an easy task. As recently published in [Moskal et al., 2013], the process of course migration towards blended learning should start at institutional level, and build its way from institutional goals and objectives through organizational capacity to proactive policy development. If applied in such a manner, the outcome would become a specific blended learning model that should not necessarily follow strict rules, and which might differ in course delivery methods from other blended learning courses [Moss and Smith, 2010, Cortizo et al., 2010]. As a support to this thesis in [Dziuban and Moskal, 2011] it is showed that there is no singular best blended learning model, and most institutions can achieve success with nearly any of them. Along with the model, there is a financial aspect that plays a significant role in the introduction of blended learning in an institution. According to [Hanover Research, 2014], expenses can be placed into three categories: development, delivery, and administrative costs. Similar top-down approach is performed in [Dini et al., 2016]. In order to lower the delivery costs some authors are seeking the possibilities of emerging technologies such as public clouds [Salah et al., 2015]. In [Mtebe and Raisamo, 2014] the authors compared the hosting costs of eLearning services on-premise and on a cloud. They found that institutions can reduce the costs by adopting a cloud-hosted approach. Pros and cons of public cloud implementation and hybrid private-public cloud implementation are discussed in [Mtebe, 2013], starting again with top-down budget breakdown. To the best of our knowledge, this is the first paper that deals with bottom-up cost estimation for blended learning, starting with a course delivery model, a platform implementation, and students' behavior.

1.2 Aims

The goal of this paper is to create a mathematical model which allows one to estimate the cost of course delivery through public cloud. In order to estimate the cost in a bottom-up manner, technical requirements for course delivery through public cloud will be presented. As a basis for the cost estimation, a model of blended learning course and a platform that supports the model will be proposed. The proposed blended learning platform will be designed as low-cost, and suitable for cloud implementation. It will be based on open-source Moodle and BigBlueButton platforms. The blended learning model will be applied and the platform will be implemented on the Amazon AWS in the example of Cisco Networking courses. In order to estimate the cost of public cloud hosting, a stress test will be performed varying both virtual hardware and number of students. Three different virtual hardware configurations will be evaluated with up to 400 students. The analysis of the stress test results will be given, along with the recommendations regarding the virtual hardware in the respect to the audience. We'll show how the cost of the course delivery vary with the number of students. It will be shown that even for the small number of students the hosting and course delivery cost can be as low as $8 per student per course. The lowest price that we achieved is $0.4 per student per course. Moreover, it will be shown that the proposed blended learning model can be customized to provide the flexibility for students regarding the time and location of learning, while maintaining highly controlled environment that supports skills building. The students' achievements will be discussed in the example of two different cohorts of students. It will be shown that students that were following the proposed learning model performed significantly better on most of given assessments.

In this paper we present the following:

- The model for blended learning courses suitable for hands-on skills building.
- The low-cost platform that supports the model for courses delivery through cloud.
- The platform stress test and the cost estimation of blended learning course delivery.
- The model and platform implementation in the example of Cisco courses.

– The students' achievements in the example of two different cohorts of students.

This paper is organized as follows. As a background on the teaching method that we use, Section 2 gives a brief introduction to Cisco courses. Section 3 presents the proposed model for blended learning. Section 4 is devoted to the design of the platform. In Section 5 we discuss and estimate the cost, give the results of the platform stress test, and evaluate the platform as well as students' achievements. The concluding remarks are given in Section 6.

2 Method

In this section we'll briefly introduce Cisco Computer Networking (CCN) courses, which will be used for proposed model evaluation. We chose the CCN courses held at our university, due to the requirements for both blended learning and strong skills building, as well as for their global recognition, reputation, and the wide scope [Cisco Online, 2018, Moss and Smith, 2010].

2.1 The scope

In the past decade several globally present IT companies have chosen philanthropy to improve their global recognition. Corporate philanthropy ultimately leads to competitive advantage and financial gain [Porter and Kramer, 2002]. However, community benefits from this kind of strategy, too. In a common act of a corporate philanthropy in education, Cisco invested in educational program, namely in the Cisco Networking Academy (NetAcad), to train computer network administrators. NetAcad program gathers a large number of academies. They support the academies, which are part of the program, in equipment, educational materials and guidelines. Educational institutions can join the program, and benefit from it in many ways [Cisco Online, 2018]. Launched in 1997, the cluster nowadays consists of more than 9,500 academies, serving over 6 million students in 180 countries [Cisco Online, 2018]. The goal of the NetAcad is to prepare students for industry-standard certification exam, while intensively building their hands-on skills.

2.2 Study plans and course management

The NetAcad offers several study levels and specializations through its member academies. Each study level and specialization consists of several separated, but closely interconnected courses [Cisco Online, 2018]. Typical NetAcad course covers 10-12 topics, called modules. Quality criteria are enforced by the NetAcad. The NetAcad recommends minimum of 40 to 80 in-class hours per course, depending on previous knowledge of the students (roughly 4 to 8 hours per module). The activities combined in the module include the usual: Learning Materials (LM) for one topic, i.e. chapter, a Chapter Exam (CE), and Chapter Labs (CL). In order to complete the course successfully, students have to pass Hands-On Skills Exam (HOSE), and the Final Exam (FE). However, the learning path and methodology are left to be designed by a particular academy.

In order to build students' hands-on skills, the academies usually choose one of three possibilities: network simulators, such as Cisco PacketTracer or GNS3 simulators, online virtual labs such as NETLAB+ [Moss and Smith, 2010, Prieto-Blázquez et al., 2008], or real networking equipment. The NetAcad recommends the usage of real equipment, supplemented by simulators and virtual labs to the extent defined by the learning model used by particular academy.

The basic learning platform, NetAcad Learning Platform (NALP), is provided by Cisco in the global act of corporate philanthropy. It is mainly intended for learning materials delivery and class management [Cisco Online, 2018]. The NetAcad program members, i.e. "academies", are required to use the NALP, but they can use their own platforms as a supplement [Moss and Smith, 2010, Cisco Online, 2018, Porter and Kramer, 2002]. The NALP is general, mainly oriented to management of students' accounts and classes, and online access to the learning materials. Alongside the learning materials and labs for each module, the NALP contains online Chapter Exams, as well as the online Final Exam. A grade book for monitoring the students' success is a part of the platform, too. The curriculum is carefully managed and regularly updated to keep track with demands and to include new technologies [Cisco Online, 2018]. Recently, the NetAcad upgraded the platform converging towards social network concept of sharing materials, but the main features remained the same.

2.3 Traditional learning model

There are different learning models and approaches that academies world-wide apply. On one hand, there are academies which are oriented towards a large auditorium, which can count several hundreds of students [Moss and Smith, 2010]. As proposed in [Moss and Smith, 2010], students study at a distance, using learning materials and platforms provided by the NetAcad and the University, and get support from their assigned tutor. The tutor periodically gives the students CE and FE assignments and evaluates their work. In order to elevate students' skills, the authors in [Moss and Smith, 2010] proposed NETLAB+ virtual lab environment during the course, with addition that the students are required to align one day with each CCNA course and spend it in the institution which is closest to them to practice hands-on skills. This activity is called a day-school, and meets the minimal NetAcad requirements [Moss and Smith, 2010]. On the other hand, there are lots of academies devoted to local population with up to 20 students per group [Cisco Online, 2018]. The policy of our academy is to focus on smaller groups and build highly trained network specialists with strong hands-on skills. The majority of our candidates are students with technical background. Thus, we apply the following learning model:

1. A course lasts for 15 weeks, with 4 hours per week, out of which 2 hours are devoted to lectures and 2 for hands-on skills practicing.
2. Students are required to take a chapter exam after each module.
3. Before proceeding to the next module, instructor comments the common mistakes on the previous chapter exam.
4. After the last module, students are required to pass the hands-on skills exam.
5. In the end, students are required to take the final exam.

3 The blended learning model

There are many proposed blended learning models which increase the learning flexibility. However, most of them lack in presence of a lecturer to guide the students through learning and hands-on skills development [Moskal et al., 2013, Moss and Smith, 2010, Cortizo et al., 2010, Nunan et al., 2000]. In that context we propose the BlendEd Learning model suitable for Hands-on Oriented courses (BELHO), shown in Fig. 1.

In the BELHO model, one cycle that covers one topic, i.e. module, starts with the lecture delivery, as in the most of the models, but it continues to hands-on skills practice (upper and lower half separated with dashed line in the Fig. 1). "The learning cycle" is carefully divided into phases to enable flexibility in scheduling of activities. The phase numbers are denoted in the right upper corners. The lecture delivery half of the BELHO model cycle starts with motivation of the students for a particular topic (phase 1, Fig. 1), which continues to online learning (phase 2, Fig. 1), where the students study at a distance, normally at home at any time, as proposed in [Moss and Smith, 2010]. However, authors in [Moss and Smith, 2010] suggest a weakly-coupled relation among students and tutor that mostly relays on an individual online support initiated by students. On the contrary, here we propose stronger relation based on mandatory synchronous activities performed in groups, in order to meet the course objectives. We introduce a new phase in the lecture delivery, performed by the instructor via online video conference (phase 3, Fig. 1). The lecture in the phase 3 is meant to be recorded to enable desired flexibility. Let us note that online learning (phase 2) and video lecture (phase 3) are time and place independent, and they can easily switch places, depending on student affinities. The hands-on practice and

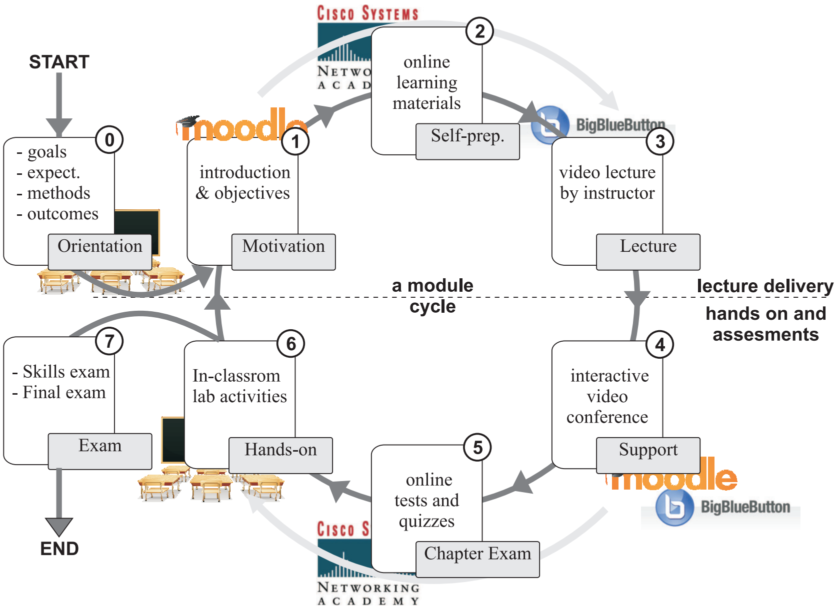

Figure 1: The blended learning model for hands-on oriented courses (BELHO)

assessment continue after the lecture delivery. This is a time when the students should systematize the knowledge, seek for a support, and are ready to practice hands-on skills (phases 4, 5 and 6 in Fig 1). Completing the phases 1, 2 and 3 the students qualify for online group discussion with the instructor about the covered topic (phase 4). They can proceed with hands-on labs in the phase 6 after successful completion of the test in the phase 5 (Fig. 1).

In order to introduce students with the learning model and usage of the learning platform, one additional phase is provided at the beginning of the course (phase 0, Fig. 1). The goal of the phase 0 is to give the students the orientation to the learning model, as well as necessary credentials to access the platform. The last but not the least, the phase 0 is significant for the students to meet the instructor who will work with them in the phases 3 and 4 at distance, and 6 in person. This gives them the sense of belonging, which is important for elevating the learning experience [Park and Jo, 2015].

Customizability and flexibility of the BELHO model from Fig. 1 lays in the fact that the cycle length, as well as the phases length and ordering of the most of the phases can be adjusted to meet the specific requirements. Moreover, the duration of the cycle and the time intervals between the phases can be modified in accordance with the institution policy. In our learning method we chose 1 week for a module cycle as in our traditional model, out of which we set 5 days for the part of the cycle from phases 1 to 4. It should be also noted that from the students perspective the phases 1, 2 and 3 are flexible and time independent, within the given period of time.

An example of customization involving the model adjustment consists of possibility to reduce the number of visits to the academy for a group or an individual student for which it is not convenient to commute to the academy frequently. In that case phases 6 from several different module cycles can be grouped. For instance, one can be allowed to come to the academy and practice hands-on skills from two or three different modules every other or third week. The bottom line, to gather all hands-on skills practice in one day, brings us back to the day-schools proposed in [Moss and Smith, 2010].

In the following chapter we discuss technical requirements and we setup the platform which supports the proposed model.

4 The platform

In order to assess the technical requirements for the BELHO model and design the learning platform, we will briefly discuss the requirements for phases from Fig 1.

4.1 Alignment of the platform with the model

The phases 1 and 2 are devoted to the distance learning, and they require learning materials to be available online. The phases 3 and 4 are dedicated to teaching, which should be done at the distance, thus those two phases require a video conferencing system. In order to support the method, the video conferencing system should have multipoint video conferencing support (phase 4, Fig. 1), and support for conference recording and streaming (phase 3). The phase 5 requires a learning platform with online quizes/tests capabilities, while the phase 6 assumes in-person hands-on skills building. From this brief model analysis, two different systems emerge as the platform building blocks: distance learning system, and video conferencing system.

Both systems are common in lecture delivery today, and there are a lot of options for choosing the systems [McKenzie et al., 2013, Ellis et al., 2016]. Seeking for a low-cost open-source and general solution, we chose the Moodle[1] as the primary learning system, while for video conferencing we chose BigBlueButton[2] (BBB). The Moodle is chosen as the primary learning system due to its generality and the ability to easily integrate any other custom learning platform, such

[1] Moodle is a free and open-source learning management system (LMS), originally developed by Martin Dougiamas, which is distributed under the GNU General Public License. URL: https://moodle.org/

[2] BigBlueButton is an open source web conferencing system, based on GNU/Linux operating system. URL: https://bigbluebutton.org/

as the NALP required for Cisco courses, while extending its features and giving the students impression of accessing only one platform. We chose BBB due to the following features:

– It does not require any special software on the client side other than standard web-browser,

– Good support and integration with Moodle,

– Ability of sessions recording and streaming,

– Up to 3 simultaneous videos, and 1 audio stream.

Video and audio streams that BBB offers are: 1 video and 1 audio stream for the instructor's camera and microphone, 1 video stream for the presentation (PowerPoint, PDF, etc.) that can be additionally used as a drawing canvas, and 1 video stream for desktop share. The instructor can utilize the special desktop share feature of BBB to stream the simulator window to students and to explain the topic further on simulated examples.

Both Moodle and BBB systems are suitable for either private or public cloud implementation[3][Salah et al., 2015]. The chosen building blocks and their relations form the Learning Platform for the BELHO model (LPB) is shown in Fig. 2.

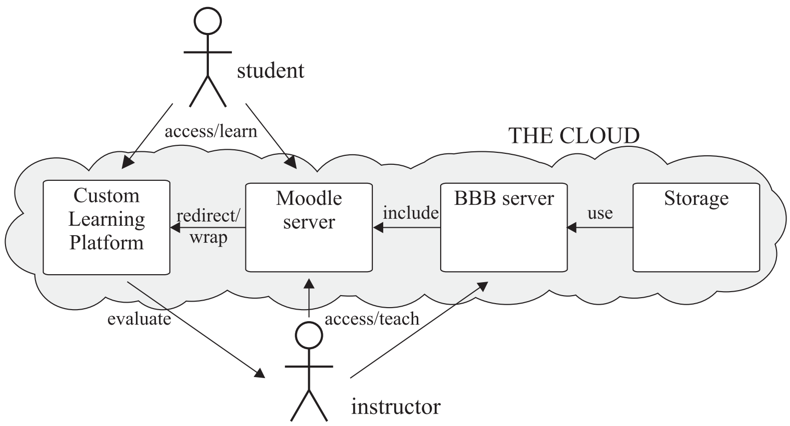

Figure 2: The learning platform for the proposed model

[3] The Amazon AWS provides a template that contains the software configuration (operating system, application server, and applications), called AMI, required to easily launch the instance with Moodle or BigBlueButton. (URL: aws.amazon.com)

The Moodle can integrate all activities from phases 1, 2 and 5, and transparently access BBB for the activities from the phases 3 and 4 (Figs. 1 and 2). For the activities required by the phases 1, 2 and 5, Moodle can either redirect or wrap the custom learning platform, if needed, as shown in Fig. 2. The BBB is an open-source project which can be easily included as a video conferencing extension of the Moodle, using available plugins for Moodle (Fig. 2). In order to store the video conference recordings, and eventually use some fault-tolerant techniques on the recorded digital material, the BBB server can be equipped with additional storage (Fig. 2). The support of LPB building blocks to respective phases of the BELHO model is denoted in Fig. 1 by background images.

4.2 The platform implementation

We implemented the LPB from Fig. 2 using, in our case, the NALP for the Custom Learning Platform as well-established and always up-to-date platform maintained by Cisco. Fig. 3 shows the students' view of the LPB.

Fig. 3 (a) shows the Moodle's common section for the entire course, containing links mostly related to students support (course forum and video conference room for the phase 4). This section is available in the upper part of the Moodle page, and it is followed by several sections, each devoted to one module. All sections devoted to the modules are standardized. Typical appearance of a module section is presented in Fig. 3 (b), and it contains: learning objectives and learning materials (available as a link to the NALP), lecture recording (given as a link to BBB Moodle plugin), additional learning materials, and online test (link to the actual CE on the NALP). The Moodle course page represents a simple and intuitive view of the LPB, which integrates different parts of the environment, capturing all aspects of the BELHO model from Fig. 1.

Fig. 3 (c) presents a screenshot of a web browser showing virtual BBB classroom, which can be seen by following BBB links (the "b" icons on the Moodle page from Fig. 3 (a) and (b)). The left column of the screen contains the list of participants and the instructor video camera stream. The central part is devoted to the drawing canvas, while the right part of the screen contains the screen share showing the network simulator.

5 Evaluation results

In this section we will discuss the cost estimation and we will present the results of model evaluation and implementation, as well as the students' achievements. First, we will develop mathematical model for cost estimation of course delivery through virtual infrastructure, regardless the course delivery model. Later we will apply the parameters of the proposed model and platform, and estimate the cost of course delivery for the example of Cisco courses.

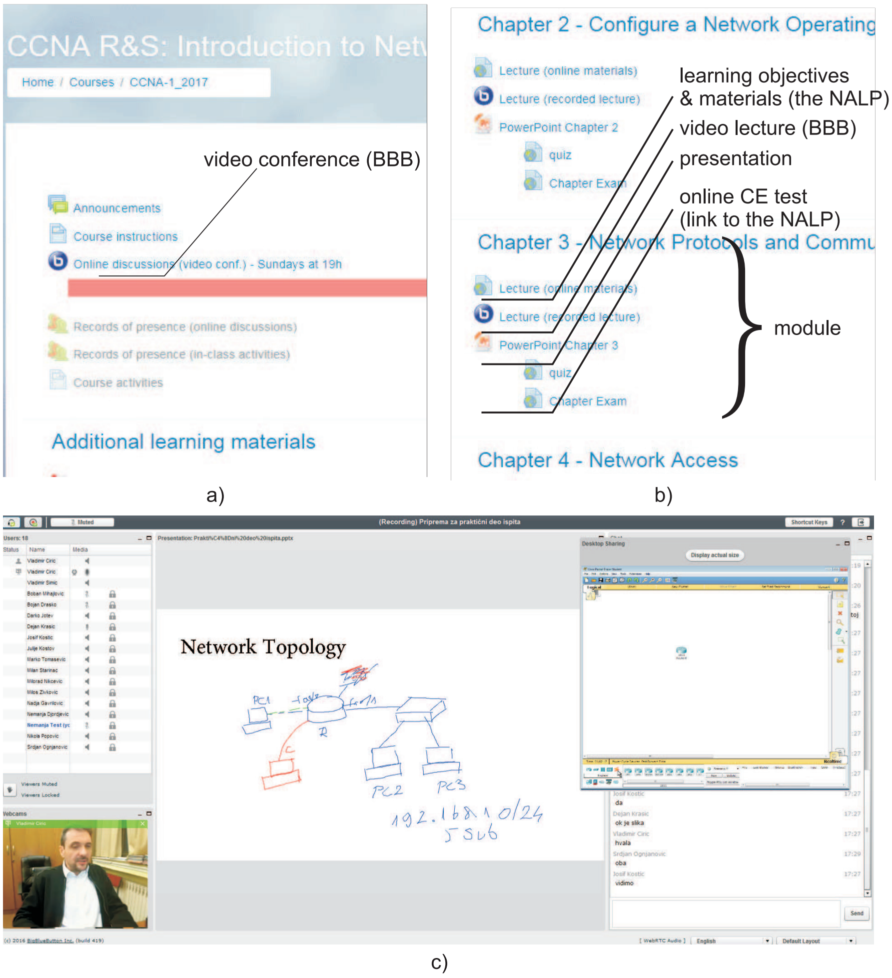

Figure 3: The LPB seen through Moodle platform from students' perspective: a) common links for the course for the support (forums, video conference room), b) typical module sections, c) screenshot of a web browser during a lecture in the virtual BBB classroom

5.1 Virtual infrastructure costs

Utilizing virtualized resources of the cloud in the form of virtual machines (VM) is called Infrastructure as a Service (IaaS). The institution can own the infrastructure as a private cloud, or it can rent resources from some of many public cloud providers for a fee [Mtebe, 2013]. The most popular IaaS provider nowadays is Amazon, with the cloud service called AWS (Amazon Web Services).

The fees for VM hosting with public cloud provider can differ from one provider to another, but the total hosting cost in general (P_H) can be calculated as

$$P_H = C + D + S + N, \tag{1}$$

where C is the total cost of utilized computational power, D is the cost of hard disks, S stands for the additional storage cost, while N includes the cost of network data transfer [Bermudez et al., 2013]. The computational power is usually charged in USD per hour or month (USD/h, USD/m). D is charged per reserved GB per month (USD/GB·m), as well as S, while N is charged per GB of transferred data (USD/GB). The difference between D and S is that D is charged per reserved disk space, while S is charged per used space. The network component (N) has two subcomponents, one per each direction of data stream: ingress and egress, which are separately chargeable elements.

The AWS offers computational power through its EC2 service (Elastic Computer Cloud) in the form of VM "instances", i.e. configurations with different number of virtual CPUs and the amount of available RAM memory[4]. Hard disks are offered by AWS through the Elastic Block Service (EBS), while additional storage has dedicated AWS service called S3 [Bermudez et al., 2013].

There are several different hosting plans. An instance is charged for the time when it is (virtually) powered on (T_C). The disks and the storage usually have the same lifetime, and they are charged for all the time the data remains in the cloud ($T_D = T_S = T_{D\&S}$). Usually $T_{D\&S} > T_C$. Thus, if the number of hosted instances is N, the total cost of hosting (P_H), including the communication, can be calculated as

$$P_H = \underbrace{\sum_{i=1}^{I} p_c^i \cdot T_C^i}_{C} + \left(\underbrace{\left(\sum_{i=1}^{I} d_i \right) \cdot p_d}_{D} + \underbrace{s \cdot p_s}_{S} \right) \cdot T_{D\&S} + \underbrace{\left(\int_0^{T_C} n(t)\, dt \right) \cdot p_n}_{N}, \tag{2}$$

where p_c,p_d,p_s, and p_n are the fees for the chosen instance type, disk, storage and network usage, respectively, while d_i is the size of the disk of i-th instance, s the size od common storage, and $n(t)$ is the function of the network data transfer over the time.

The therm $\int_0^{T_C} n(t)\, dt$ in (2) gives the total amount of data transferred over the time. In words, the total cost P_H is the sum of: the cost of I utilized instances ($p_c^i, i = 1, 2, ..., I$) for the time they are powered on (T_C^i); the disk cost (p_d), times the sum of disk sizes of all instances ($\sum d_i$); the storage cost (p_s), times the amount of stored data (s); and the amount of transferred data $\int_0^{T_C} n(t)\, dt$, times the price per transferred data unit (p_n.)

[4] URL: https://aws.amazon.com/ec2/instance-types/

5.2 Resources estimation

In order to determine the parameters of Eq. (2) for the case of the platform from Fig. 2, and to estimate the cost of course delivery which follows the model from Fig. 1, we will briefly discuss the platform requirements.

5.2.1 The network

As previously mentioned, the BBB offers the instructor one audio and three video streams. The network requirements for the Moodle server (Fig. 2) can be neglected compared to the video streaming requirements of BBB. The video from instructor's camera can be streamed in three different resolutions: 320x240px, 640x480px and 1280x720px. We will refer to them as R_1, R_2 and R_3, respectively. Having in mind used video encoding, the required bandwidth is approximately 0.25, 0.4 and 0.6 Mbps for R_1, R_2, and R_3. Video stream for the presentation and a drawing canvas, due to the feature of the content of that particular stream to change only occasionally, have the order of magnitude about 0.1 Mbps. However, the video stream for desktop sharing is significantly demanding and it strongly depends on the size of a shared screen portion, as well on the screen resolution. This can be as low as 0.1 Mbps, and as high as 2 Mbps. The audio encoder gives about 0.01 Mbps per audio stream.

In a typical scenario, the instructor is the only one broadcasting any stream, while students are viewers only. The instructor broadcasts audio stream constantly, while the students can occasionally broadcast their audio, if allowed. Having that in mind, as well as the fact that the audio stream can be neglected compared to video streams, ingress and egress bandwidth from the server (B_{in}, B_{eg}), as well as the students' bandwidth requirements (B_S), can be estimated as

$$B_{in} = \sum_{i=1}^{3} V_i, \quad B_{eg} = N_S \cdot \sum_{i=1}^{3} V_i, \quad B_S = \sum_{i=1}^{3} V_i, \tag{3}$$

where N_S is the number of the students, while V_1, V_2 and V_3 stand for instructor's video streams. Let us note that through the term B_{eg} from (3), the number of students that follow the course (N_S) has influence on the cost of virtual infrastructure hosting and course delivery (the component N in eq. (2)).

Table 1 shows the bandwidth requirements estimated from (3) for different video resolutions, for the scenario with one instructor and many listeners. This scenario is of a particular importance for the proposed model, due to the activities of the phase 4 of the model from Fig. 1. For example, for the lecture where the instructor has a camera operating with R_2 resolution, and a group of 20 students, the required bandwidth, according to (3), is $B_{in} = 0.4$ Mbps, and $B_{eg} = 8$ MBps (Table 1). The students' web browser consumes $B_S = 0.4$ Mbps.

The no. of stud.	R_1			R_2			R_3		
	B_{eq} [Mbps]	B_{in} [Mbps]	B_{in}+B_{eq} [Mbps]	B_{eq} [Mbps]	B_{in} [Mbps]	B_{in}+B_{eq} [Mbps]	B_{eq} [Mbps]	B_{in} [Mbps]	B_{in}+B_{eq} [Mbps]
5	1.25	0.25	**1.5**	2	0.4	**2.4**	3	0.6	**3.6**
10	2.5	0.25	**2.75**	4	0.4	**4.4**	6	0.6	**6.6**
20	5	0.25	**5.25**	8	0.4	**8.4**	12	0.6	**12.6**
50	12.5	0.25	**12.75**	20	0.4	**20.4**	30	0.6	**30.6**
100	25	0.25	**25.25**	40	0.4	**40.4**	60	0.6	**60.6**

Table 1: The estimate of network requirements for scenario when only video camera is used

For the sake of illustration, we captured a one-hour sample lecture with different classroom settings, delivered to a group of 17 students. The screenshot is shown in Fig. 3 (c). The recording of the lecture was turned on, while the network bandwidth, as well as the computational resources usage were measured. The instructor has used the R_1 resolution for his video camera stream. Fig. 4 (a) shows the consumed bandwidth during the lecture, and it represents the function $n(t)$ from (2). Vertical axis stands for the bandwidth in kbps, while the horizontal axis shows the exact time. Ingress (B_{in}), egress (B_{eg}) and the total bandwidth consumption ($B_{in} + B_{eg}$) are given in Fig. 4 (a) as dashed, doted and solid line, respectively.

The time axis is divided into 6 segments in which the instructor has used different video streams settings for the sake of illustration. The video streams provided at different intervals of time during the lecture are given in Table 2. From Fig. 4 (a) and Table 2 it can be noticed that the 2nd segment, which lasts the longest, corresponds to the estimate given in Eq. (3) and Table 1. The minimum bandwidth requirement was achieved during the 3rd time segment, when the instructor's video camera was turned off and only presentation i.e. drawing canvas was used. During that time the consumed bandwidth was slightly less than 2 Mbps in total, which is in accordance with Eq. (3). The desktop share showing the PacketTracer network simulator (Fig. 3 (c)) increased the bandwidth to nearly 10 Mbps for 17 simultaneously present students in segments 4 and 5, as shown in Fig. 4 (a).

The results given in Fig. 4 capture all BBB usage scenarios. However, the proposed model requires only two different settings. One setting is the virtual classroom with the instructor only, sharing some or all of the available video streams, while recording the lecture without students' presence (phase 3 in Fig. 1). In this setting network requirements are very low, due to the absence of students at the time of the recording, i.e. the complete dominant component B_{eg} is eliminated (dotted line in Fig. 4 (a)). The other setting is used for the online support during discussion hours (phase 4 in Fig. 1). This setting requires network bandwidth that follows the guidelines given by (3) and presented in Table 1 and Fig. 4 (a). If a number of the students is extremely high and network

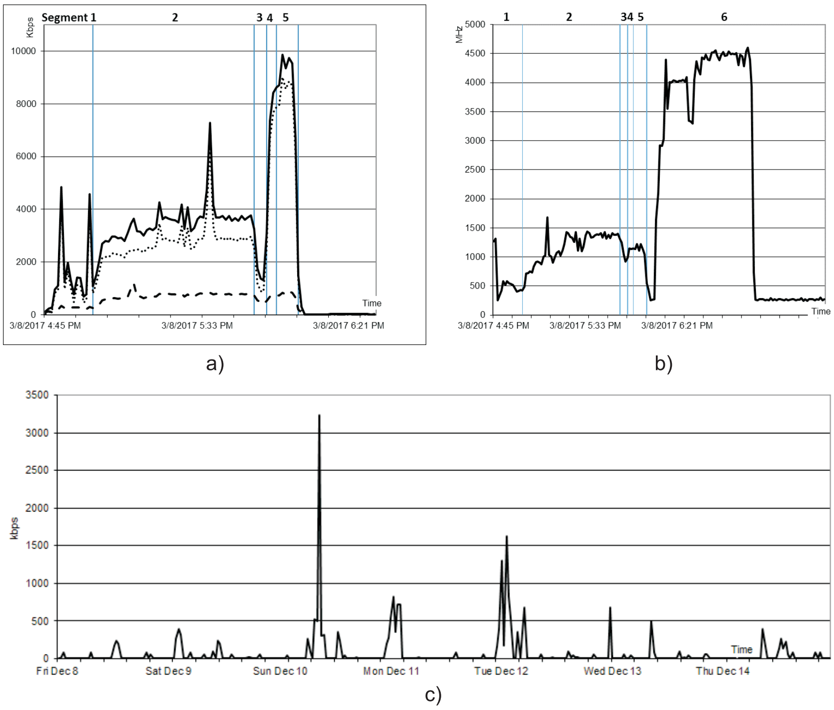

Figure 4: Network bandwidth and computational requirements for the lecture in the virtual classroom: a) consumed bandwidth, b) the CPU usage, c) typical server bandwidth consumption over one-week period

The segment	Inst.'s v. camera	Drawing c. presentation	Screen share	No. of streams	Description
1	No	No	No	0	Students are joining
2	Yes	Yes	No	2	Lecture in progress
3	No	Yes	No	1	Lecture in progress
4	No	Yes	Yes	2	Lecture in progress
5	Yes	Yes	Yes	3	Lecture in progress
6	No	No	No	0	Post-processing

Table 2: Description of the time segments from Fig. 4

requirements go beyond the available bandwidth, the instructor can decide to lower the video camera resolution, or even to turn that stream off, leaving the audio stream along with presentation and drawing canvas.

Nevertheless, the complete and dominant component B_{eg} is eliminated from the activity of lecture recording. It is still present, but it is spread over time when the students access the lecture. As the model allows the flexibility in time when the students access the environment to learn, it is unlikely that most of the students will access the environment at the same time, which can be observed from Fig. 4 (c). The network bandwidth is captured over one-week period of the environment usage and is shown in Fig. 4 (c). From Fig. 4 (c) it can be seen that the online discussion and support (the phase 4 in Fig. 1) was organized and lasted for a half an hour on a Sunday afternoon, where the peak was recorded for the relatively short period of time.

5.2.2 Hard disk and storage

Hard disk requirement is conditioned by the chosen operating system. The storage requirements are as follows. The instructor's audio stream with the presentation or drawing canvas requires 110 MB per recorded hour (Mbph) for RAW recorded materials, or 10 MBph for post-processed materials. If the instructor's video camera is added, 130 MBph are required for unprocessed and 50 MBph are required for post-processed materials. When all three streams are used simultaneously, they require 240 MBph and 75 MBph for RAW and post-processed materials, respectively.

5.2.3 The computational power

Fig. 4 (b) shows the CPU usage of the BBB server (Fig. 2). The last, 6th segment in both Figs. 4 (a) and (b) represents the time period after the lecture, when the classroom was empty, and when the server has started post-processing of the recorded session. Fig. 4 (b) shows CPU usage. The vertical axis in Fig. 4 (b) stands for the cumulative usage of available CPUs in MHz. It can be seen from Fig. 4 (b) that the session post-processing utilized more than one CPU for nearly an hour, while the lecture itself had moderate requirements, for a given number of students. It should be noted that the post-processing is not a real-time event that is time critical, but the more the resources it has for processing, the sooner the recordings will be available for the students, and vice versa. The additional feature of the BBB is the ability to schedule post-processing at off-peak hours, which was not employed here. In our virtual classroom, with relatively small number of students (Fig. 4), the RAM consumption did not exceeded 4 GB, while the average active memory was between 1 and 2 GB. However, in order to be able to give a general conclusion and recommendation for virtual hardware configuration, in the following section we give a detail results of the stress test with up to 400 students on different virtual configurations.

5.3 The stress test results and the system cost estimation

The platform from Fig. 2 was tested using three different AWS instance types: t2.small (1 vCPU, 2 GB RAM), t2.medium (2 vCPUs, 4 GB RAM), and t2.large

(2 vCPUs, 8 GB RAM). We setup Linux CentOS 7 with Moodle v3.2 and Ubuntu 16.04 with BigBlueButton v1.1. Each instance has 25 GB of EBS disk reserved for operating system and applications. AWS S3 is used as associated storage (Fig. 2).

In order to perform the stress test and determine the boundaries of the system usage, we connected one instructor with one audio and one video stream in R_1 resolution, and we used 80 physical personal computers to create and simulate students connected to BBB server. The connection rate was one newly connected user per each 10 - 20 seconds. We created 5 - 10 connections per physical personal computer. During the test we: (1) observed the system behavior, and (2) measured objective system parameters of BBB server. Considering the overall behaviour of BBB server, we were focused on the appearance of three events: (E1) the first time occurrence of the event that system kicks out one of already connected users due to the system load; (E2) the time needed for establishing a new connection significantly increases; (E3) the limit is reached, i.e. the system disconnects more already connected users than the number of new users who manage to connect to the system. Table 3 gives the virtual hardware configurations, as well as the number of users for which the events E1 - E3 were noticed.

Configuration	vC_1	vC_2	vC_3
Moodle	t2.small		
BBB	t2.small	t2.medium	t2.large
E1	80	200	290
E2	140	300	300
E3	415	371	400

Table 3: Virtual configurations used for the platform stress test

The objective BBB parameters measured during the stress test reflect the observations from Table 3. The results of the BBB stress test are given in Fig. 5, and they are aligned with findings presented in [Vasconcelos et al., 2016]. We were measuring the following: memory consumption (Fig. 5a); CPU utilization including user and kernel code, and IO wait time (Fig. 5b); and network throughput (Fig. 5c). Fig. 5a shows the amount of memory used by user and kernel processes, excluding the memory that Linux uses for buffering and disk caching. From Fig. 5a it can be seen that the utilized memory is increasing slowly between 1.1 and 1.6 GB for all three instance types, for the number of users up to 400 (the event E3 from Table 3). This corresponds to the results presented in [Vasconcelos et al., 2016], as well. Thus, we can conclude that the memory is not a limiting factor, and that t2.small instance is sufficient, while t2.medium is recommended due to the larger amount of memory available for disk caches and buffers.

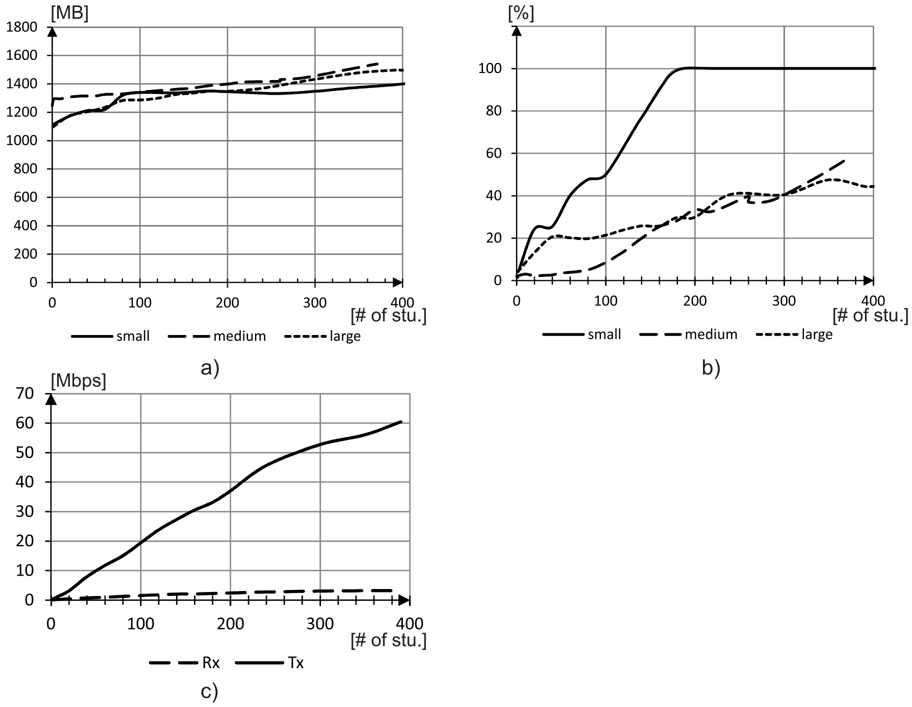

Figure 5: Stress test results: a) used memory, b) CPU utilization, c) network throughput

Fig. 5b shows CPU utilization. The official BBB documentation recommends the CPU load below 80% for system stability. This also reflects to our findings: the event E1 for t2.small instance appeared with 80 users (47% of CPU load, Fig 5b), and the event E2 started with 140 users (76% of CPU load). We were able to connect more than 400 users (Table 3), but we don't recommend this instance type for more than 120 - 140 users due to the frequent connection losses and slow connection times. The optimum is up to 80 users, when the first disconnections appeared (E1, Table 3). The instance t2.medium with its 2 vCPUs performed much better, as expected (see Table 3 and Fig. 5b).

Having in mind the results of the system stress test, we can conclude that virtual hardware configuration vC_1 (Table 3) can be used for up to 80 users, while configuration vC_2 is recommended for up to 200 - 250 users. We didn't notice any significant difference with virtual configuration vC_3. Let us note that further increase of the number us users would require different architectural approach and utilisation of load balancers.

In order to estimate the cost of the platform hosting, we apply the parameters of the model from Fig. 1 to Eq. (2), along with the corresponding AWS costs in the case of virtual configurations vC_1, vC_2 and vC_3:

- N – The number of required VM instances is $N = 2$.
- $T_C, T_{D\&S}$ – The total course length is 3 months. Both VM instances were powered on all the time, due to the requirements of the model. Thus, $T_C = T_{D\&S} = T = 3$ $[mo]$.
- p_c^1, p_c^2 – The t2.small instance fee is 10.52 [USD/mo] (1 year contract, no upfront payment). The t2.medium instance fee is 20.96 [USD/mo], while t2.large instance fee is 41.98 [USD/mo].
- d_1, d_2 – Both instances have $d_1 = d_2 = 25$ [GB] of EBS.
- p_d – 0.10 [USD/GB·mo].
- s – Required storage for keeping 2 hours of both RAW and post-processed lecture recordings per week, 15 weeks per course is $(130\ [\text{MB}/h] + 50\ [\text{MB}/h]) \cdot 2h \cdot 15w = 5400\ [\text{MB}] \approx 5.4\ [\text{GB}]$.
- p_s – 0.0255 [USD/GB·mo].
- p_n – 0.08 [USD/GB].

The cost of the network data transfer N from Eq. (1) is directly proportional to the number of students, i.e. $N = \left(\int n(t)dt\right) \cdot p_n = (N_S \cdot E_S) \cdot p_n$, where E_S is the expected data transfer per student per course. If we assume that the amount of post-processed recordings is about $50\ [\text{MB}/h] \cdot 2h$ per week, we expect $E_S = 100[\text{MB}] \cdot 12[w] = 1.2$ [GB] per course per student, i.e. ca. $E_S = 1.5$ [GB], including online weekly consultations.

Having in mind the previous parameters, the estimation of the platform hosting costs per course (P_H) are given in Table 4. The hosting cost per student per course is derived from the Table 4 as P_H/N_S and given in Fig. 6

It should be noted that, in one hand, the real cost of course delivery P_H may differ from the estimation due to the approximation of network traffic. However, having in mind the value of p_n, the obtained cost well-estimates the real cost.

However, in order to be able to compare the costs of blended learning with traditional learning, we need to take into the account non-platform related costs as well (e.g. manpower costs, location-related costs, energy costs), since those

N_S		10	20	40	80	120	160	200	280	360
$N_S \cdot E_S$ [GB]		15	30	60	120	180	240	300	420	540
N [$]		1.2	2.4	4.8	9.6	14.4	19.2	24	33.6	43.2
P_H [$]	vC_1	79.74	80.9	83.34	88.14	n.r.	n.r.	n.r.	n.r.	n.r.
	vC_2	111.06	112.26	114.66	119.46	124.26	129.06	133.86	143.46	153.06
	vC_3	n.r.	n.r.	n.r.	182.52	187.32	192.12	196.92	206.52	216.12

* n.r. - not recommended

Table 4: The cost of AWS virtual infrastructure per course

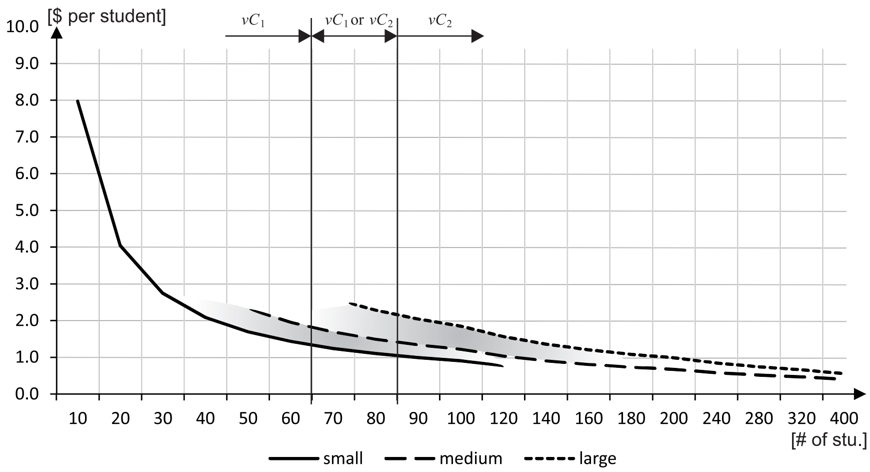

Figure 6: The cost of AWS virtual infrastructure per student per course

also contribute to the difference with respect to traditional courses. The total cost can be estimated as

$$P_T^{(b)} = P_P^{(b)} + P_H^{(b)} + P_E^{(b)} + P_I^{(b)}, \tag{4}$$

for the case of blended learning courses, and as

$$P_T^{(t)} = P_P^{(t)} + P_H^{(t)} + P_E^{(t)} + P_I^{(t)}, \tag{5}$$

for the case of traditional courses, where P_P stands for the course preparation costs, P_E represents lab. equipment costs, including the energy consumption costs, while P_I stands for the instructor costs. The relative relationship between the cost components P_P, P_H, P_E, and P_I is such that: $P_P^{(b)} > P_P^{(t)}$, due to the time required to setup the platform for the first time; $P_H^{(b)} > P_H^{(t)} \to 0$, because the traditional courses usually require hosting of static content mostly;

$P_E^{(b)} < P_E^{(t)}$, due to the fact that the part of the classes is not held in the classroom anymore; and $P_I^{(b)} < P_I^{(t)}$, because the instructors are required to record the courses only for the first time, and later they can reuse the online part of the lectures many times.

Having all previous in mind, it is difficult to draw a general conclusion about $P_T^{(b)}$ and $P_T^{(t)}$ due to the large differences of equipment, energy and manpower costs around the world. However, we can say that in our case the P_I component was dominant, thus, after initial setup of the platform and recording of the course materials we managed to decrease costs significantly, i.e. the cost of the platform hosting was significantly below the difference of the instructor costs $P_H^{(b)} < \left(P_I^{(t)} - P_I^{(b)}\right)$.

5.4 Student performance

For the sake of model evaluation we enrolled two groups of students, each with $N_S = 14$ students. We refer to these groups as G1 and G2. The group G1 is the control group that follows the traditional model, while the group G2 is the test group that follows the proposed BELHO model from Fig. 1. Both groups were enrolled in the course "Introduction to Networks" from CCNA Routing and Switching program. They followed the same curricula, and had the same instructor. The group G1 started in February and finished in June 2017. The group G2 started in December 2017 and finished in March 2018.

With aim to show suitability of the proposed model (Fig. 1) for hands-on oriented courses, such as Cisco Networking Academy courses, we compared CE results from both groups G1 and G2 for corresponding modules. A null hypothesis is that the average scores in particular CE test were equal in both groups, and an alternative hypothesis is that the average scores in CE test were significantly different between groups. More than 150 results per group from CE tests were obtained during the experiment. The results are given in Table 3, where each column stands for the students' scores on one chapter exam. Mean values and standard deviations (SD) are given. In cases where CE results in both groups satisfied normality criteria (tested using Shapiro-Wilk test), Student t-test was performed in order to compare means. In other cases, Mann-Whitney test was used. The last row in Table 3 presents corresponding p-values. Alpha value 0.05 is accepted in all tests. Students in the group G2 performed significantly better on 7 of 11 CE tests (given in bold in Table 3). For the remaining four results of the CE tests (Table 3), we can claim that G2 didn't performed worse than G1.

The previous knowledge of the students from both groups was measured, too. At the beginning of each course students were given initial pre-test. The students from G1 scored 64.5 out of 100 points in average on the pre-test, i.e. 64.5% (SD=19.75), while the students from G2 achieved 63.0% (SD=28.47).

Groups do not statistically differ in previous knowledge (p=0.466). Thus, we can conclude that significantly better results on most of CE tests were sourced from the learning model.

Group	CEs - Mean (SD)										
	1	2	3	4	5	6	7	8	9	10	11
G1	86.1 (5.96)	88.3 (8.05)	89.6 (8.18)	89.2 (9.56)	93.4 (7.01)	92.7 (6.69)	91.1 (7.03)	91.0 (9.45)	92.7 (6.56)	90.2 (9.65)	91.4 (8.29)
G2	89.7 (10.72)	95.3 (4.11)	90.1 (15.18)	99.3 (1.05)	96.2 (5.04)	98.9 (2.82)	98.3 (2.21)	93.1 (8.50)	95.3 (4.11)	96.6 (4.37)	98.5 (1.60)
p-value	**0.041**	**0.004**	0.194	**0.005**	0.118	<**0.001**	**0.007**	0.240	0.110	**0.032**	**0.001**

Table 5: The students' achievements on the Chapter Exams

The improvement can be explained with the fact that the students from G2 had more time to study before the hands-on skills practicing. The hands-on skills practicing in the model from Fig. 1 serves as both skills practicing and the recapitulation of learned knowledge.

6 Conclusion

In this paper a mathematical model which allows one to estimate the cost of course delivery through a public cloud is developed. In order to estimate the cost in a bottom-up manner, technical requirements for course delivery through a public cloud are presented. As a basis for the cost estimation, a model of blended learning and a platform that supports the model are proposed. The proposed model enforces the instructor to be present during the learning process, and to help students build solid hands-on skills. The model can be characterized as a flexible and customizable blended learning model that preserves the quality of hands-on skills practicing, giving the students flexibility by enabling distance learning. The proposed platform is low-cost, and based on open-source Moodle and BigBlueButton platforms. It is designed to be suitable and simple for cloud implementation. The model and the technical characteristics of the platform are described in detail. The proposed model is applied and the platform is implemented on the Amazon AWS in the example of Cisco Networking courses. In order to estimate the cost of public cloud hosting, a stress test is performed varying both virtual hardware and the number of students. The cost function in the respect to the number of enroled students is given. It is shown that even for the small number of students the hosting cost can be as low as $8 per student per course. The lowest price that we achieved is $0.4 per student per course. Moreover, it is shown that the proposed blended learning model can be customized to provide the flexibility for students regarding the time and location of learning, while maintaining highly controlled environment that supports skills building. The students' achievements are discussed in the example of two different cohorts of students. It is shown that students that were following the proposed learning model performed significantly better on most of given assessments.

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