Adaptive remote experimentation for engineering students

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ABSTRACT

Due to the dynamic nature of changes in various ICT technologies nowadays, the gaps between industry, research, and academia need to be bridged in order to adequately support STEM students towards their future career paths. With the COVID-19 pandemic, and restrictions on access to university premises, an agile transition of both teaching and experimentation was essential, and adjustments in the curriculum were needed more than ever. Therefore, in this paper we present an adaptive and on-demand education framework for engineering students, thereby enabling remote experimentation and adjustments of exercise content to enhance students' learning experience. We present the two types of practical experimentation environments, i.e., cloud and real-life net-working testbed, for performing remote laboratory exercises, as well as the assessment of students' experience that is used as an input for the dynamic adjustments of the exercise content. Our results show that students consider they significantly improved the baseline skills our courses tend to build and strengthen towards preparing students for their future jobs.

CCS CONCEPTS

• Computing methodologies → Distributed computing methodologies; **• Applied computing → Interactive learning environments**; **• Networks → Network protocols**; **Programming interfaces**.

KEYWORDS

STEM education, adaptive learning, on-demand remote experimentation, engineering courses, IEEE/CS joint curricula.

1 INTRODUCTION AND BACKGROUND

The rapid development of Information and Communications Technology (ICT) is not only shaping up the industry, and spawning new research directions, but it is also highly affecting academia and learning process within the Science, Technology, Engineering, and Mathematics (STEM) education. Thus, various curriculum adjustments are required, to keep up the pace with new trends in different industry and research fields, and to equip students with the competitive skills [6, 8]. The teaching methods and practices for hands-on experimentation in different engineering and computer science fields have evolved along with the digitalization trend, but due to the COVID-19 pandemic and restrictions that universities imposed towards access to laboratory premises, these practices and teaching frameworks have undergone a significant change. In remote learning environments, both educators and students are still trying to find the most efficient approach to cope with the new challenges. The transition from the University to the ICT industry needs to be supported and facilitated by applying adaptations in the learning process, as well as in the laboratories. Thus, as there is no *one-size-fits-all* teaching model that suits all students, teaching frameworks need to be adjustable, i.e., to offer instructions customized to specific class [9].

Yan [10] introduces a self-paced online learning, i.e., an adjustable model for online education that focuses on asynchronous and individualized study. However, as stated by Yan [10], a significant drawback of such model is a lack of academic support for students since there is almost no social interaction, including no formative feedback, and no control over the students' learning curve. To facilitate the learning process, Yan [10] identified the three essential technical and pedagogical strategies, i.e., formative assessment e.g., polls, surveys, quizzes, etc.), adaptive assessment (e.g., personalized questions), and learning analytics, which, if combined, can create a viable solution for providing academic support to students in an online learning environment [10]. Furthermore, the concept of mastery learning [5] adjusts the instruction based on the time that is required for different students to learn the same unit. The essential procedures that mastery learning consists of are: i) setting learning objectives for each topic, ii) breaking topics into smaller sub-topics, and adjusting the learning objectives to each sub-topic, iii) defining a predetermined mastery-level criteria for students that needs to be met before they move to the next (sub-)topic, and iv) allowing each student to practice all what is learnt, and to provide feedback [5].

To make labs for practical teaching more accessible for students, and to enhance training of students' skills, most of the efforts to modernize STEM laboratories fit into the following three categories: i) the hardware-based labs and testbeds [3], ii) the cloud-based labs that can be realized either as a shared cloud solution on the university level [1, 4], or by purchasing resources in public cloud platforms (e.g., Amazon Web Services (AWS)) [4], and iii) providing remote laboratories that consist of physically equipment that is

Table 1: Goals of our research.

Goal	Description
Goal 1	To adjust our teaching methods and course material according to students' knowledge and learning pace.
Goal 2	To enhance students' knowledge and practical skills that will prepare them for their future ICT-related jobs.
Goal 3	To provide students with remotely accessible laboratories that will enable experimentation on-demand, and in an unrestricted manner, without the need to possess high-performance equipment at home.

remotely accessible (e.g., LabsLand - Remote laboratory concept[1]). Thus, the ultimate goals of our research are: i) To adjust our teaching methods and course material according to students' knowledge and learning pace, ii) To enhance students' knowledge and practical skills that will prepare them for their future ICT-related jobs, and iii) To provide them with remotely accessible laboratories that will enable experimentation on-demand, and in an unrestricted manner, without the need to possess high-performance equipment at home, as shown in Table 1.

To do so, in this paper we present an adaptive and on-demand educational framework that consists of i) two types of practical experimentation environments, i.e., cloud and testbed, for performing remote laboratory exercises with engineering students, and ii) assessment of students' experience that is used as an input for the dynamic adjustments of the exercise content. These adjustments are performed on-the-fly in order to customize both the exercise content and the teaching methods to the students' level of understanding the course matter.

2 EDUCATIONAL FRAMEWORK FOR ADAPTIVE REMOTE EXPERIMENTATION

In this section, we present our educational framework that aims at improving overall students' learning experience by applying adaptation and adjustments in laboratory exercises based on the formative assessments of students' knowledge, and their feedback in the form of survey. This educational framework is applied to two academic courses, i.e., Distributed Systems and Network Management, which are part of the third year within Bachelor study at the University of Antwerp, Faculty of Applied Engineering[2]. As presented in our research articles [2, 7], the Distributed Systems course is mapped to the ACM/IEEE CS2016 joint curriculum for computer science engineering [7], and the Network Management to the ACM/IEEE Computer Engineering Curricula 2017 (ACM/IEEE CE2017) [2]. Firstly, we provide insights into our two practical experimentation environments, i.e., cloud and real-life networking testbed, for performing remote laboratory exercises. Secondly, we briefly overview the process of adjusting educational framework, i.e., its maintenance.

[1]LabsLand: https://eeti.uga.edu/online-learning/

[2]Bachelor of Electronics and ICT Engineering Technology program: https://www.uantwerpen.be/en/study/programmes/all-programmes/ba-electronics-ict-engineering/study-programme/

2.1 Cloud and testbed experimentation environments

In the scope of the Distributed systems module, last year we switched to the experimentation in a remote cloud environment (as described in our paper [8]), from the Raspberry Pi-based laboratory presented in [7]. For the practical part of the course, students are working on the project in teams, and they are expected to design and develop a distributed file system with nodes placed in a ring topology, thereby using java programming language. Each of the student groups is assigned with a cluster of five Docker containers with the same IP address and different port mapping, and such Network Function Virtualization (NFV) resources are managed by Portainer[3], which allows educators to monitor the remote nodes and students' progress. The scalability of such remote laboratory is evident, as all students' containers can be easily healed if any failure occurs, and more nodes can be assigned to groups if they need them for testing, or in case of a boosted enrollment. To access their remote lab, students do not need any specialized equipment, but just a PC/laptop that can access remote nodes via Command Line Interface (CLI). Importantly, students can work on their tasks in the project in a flexible manner with no time restrictions.

For the course of Network management, we pursue an experimentation in a real-life environment by utilizing the CityLab Smart City testbed[4], which is a smart city large-scale wireless network testbed. This testbed enables experimentation on the nodes that are attached to buildings and streetlamps in Antwerp (Fig. 1), Belgium, using the segments of unlicensed spectrum. We make use of this testbed to bring theoretical concepts of NFV, Software Defined Networking (SDN), and network monitoring, into practice. The live practical sessions consisted mainly of the deployment of essential NFV to provide basic connectivity to clients. Those functions vary from DHCP and DNS, to OpenVSwitch and wireless Access Points deployed along the city. All deployments are based on containerization technologies (e.g., Docker), in order to prepare the students to the new standards of industry. Beyond that, the students also have a hands-on experience setting up traffic shaping and filtering using OpenFlow rules. Finally, as knowledge of network monitoring is essential for a Network Management course, each student also deploys an instance of Prometheus[5], a monitoring and alerting tool that is being adopted by many companies, in order to have an initial contact with a monitoring system. To deepen their understanding of such systems, their last task is to design and deploy their own monitoring tool using Python.

2.2 Maintenance of the educational framework

In Fig. 2, the whole process of maintaining the educational framework is illustrated. This framework is not tied to any specific engineering course, but it is rather a generic framework that can be applied to any course that follows a similar structure, i.e., theoretical and practical teaching. Once the educational framework is created, the closed-loop process of framework maintenance begins with theoretical lectures. In our two courses considered in the case study, the lectures and laboratory exercises are not performed in

[3]Portainer: https://www.portainer.io/

[4]CityLab: https://doc.ilabt.imec.be/ilabt/citylab/index.html

[5]Prometheus: https://prometheus.io/

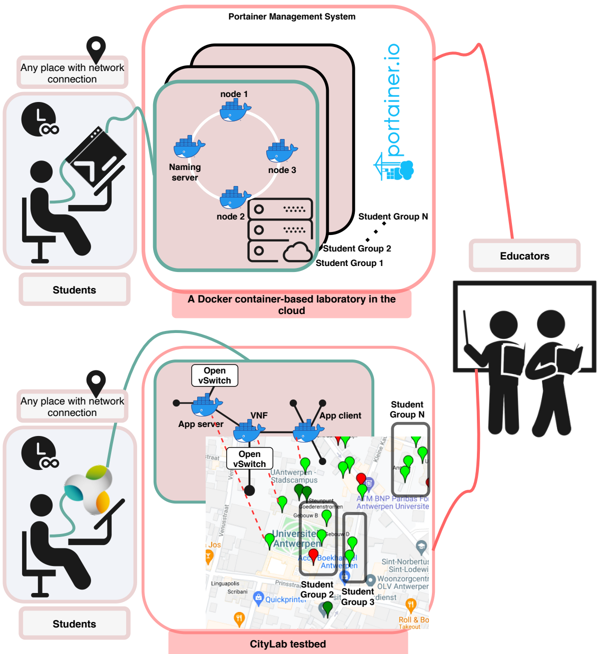


Figure 1: Cloud and the testbed environment.

parallel, but due to the COVID-19 pandemic, both are delivered online by utilizing the Blackboard Collaborate platform[6]. All theoretical concepts of distributed systems and network management are taught first, and then educators proceed with the experimental part, where students put their learnt concepts into practice. Another closed-loop maintenance is being performed on an even more granular level, i.e., on the laboratory exercises. Along with the practical experimentation in different environments, which are described in Section 2.1, educators apply formative assessment of students' knowledge in the form of polls and short quizzes. Based on the results of this assessment procedure, educators decide to adjust the content of the ongoing laboratory exercise, as well as the upcoming exercises, to the students' level of understanding. The adjustments of the content usually mean putting more focus on the weak points in students' knowledge, thereby trying to provide an additional explanation with practical examples. The same process is repeated in each of the laboratory sessions until the end of semester, when we ask students to provide us with their overall feedback in the form of an extensive survey (as presented in Section 3). As pointed out in Section 1, there is a constant need to find a balance between the knowledge students acquire at the university and the real requirements for their skills on the job market. Thus, educators in our framework pursue research of advancements in ICT fields, with the focus on distributed computing, virtualization, network management, and networking technologies, in order to enhance both theoretical and practical exercises for the next academic year. Along with the research of state-of-the-art technologies, educators analyze students' success at the end of semester, and together with the students' feedback, they apply changes in the curriculum if needed, and update the educational framework, as shown in Fig. 2.

[6]Blacboard Collaborate: https://au.bbcollab.com/

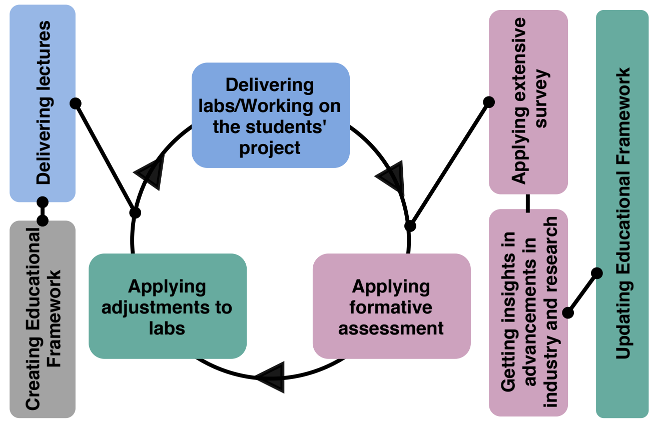


Figure 2: The process of adjusting educational framework.

3 ASSESSMENT OF STUDENTS' EXPERIENCE

As introduced in Section 2, the comprehensive survey as a feedback from students is collected at the end of semester, to gather the means for improving and updating educational framework. In this section, we first present the survey as a collection of different groups of statements that we asked students to evaluate, and second, we present and discuss the results that were retrieved after performing quality analytics. In total, 33 out of 36 students responded to our survey for the Distributed systems course, and 8 out of 18 for the Network management. All students were male, aged between 21 and 22, and all of them followed both courses.

3.1 Student survey

In Table 2, we show six groups of statements, which aim to assess students' experience with our educational framework. Furthermore, all of them are mapped to particular goal defined in Section 1 (Table 1).

- *Group 1 - General quality of lectures and lab exercises*: Assesses students' feedback on the general quality of lectures and laboratory exercises, and pursues to achieve Goal 1 of our educational framework, which is introduced in Section 1. The main rationale behind this group is to check whether there are any major issues in the organization of the course, as they might impact significantly students' learning process and their overall success. Some of these issues might be i) lack of background knowledge that is required to follow either theoretical or practical part, ii) incompatibility between lectures and labs, iii) impact of the online teaching, and iv) teaching students in a foreign language.
- *Group 2 - Adaptive and personalized learning in labs*: Focuses on students' perception on how adjustable and how adapted labs are, and whether lab recordings, polls as a formative assessment, and unrestricted use of lab resources, help them to improve their understanding or not. This group of statements helps to achieve Goal 3 (Table 1).
- *Groups 3 and 4 - Flexible classroom environment & Testbed vs. Cloud vs. Local*: Support Goal 2 of our educational framework (Table 1), as they tackle flexibility of our lab environments, and opportunities to practice important skills regardless of the equipment students have at home. Further, we assess

Table 2: Survey statements/questions.

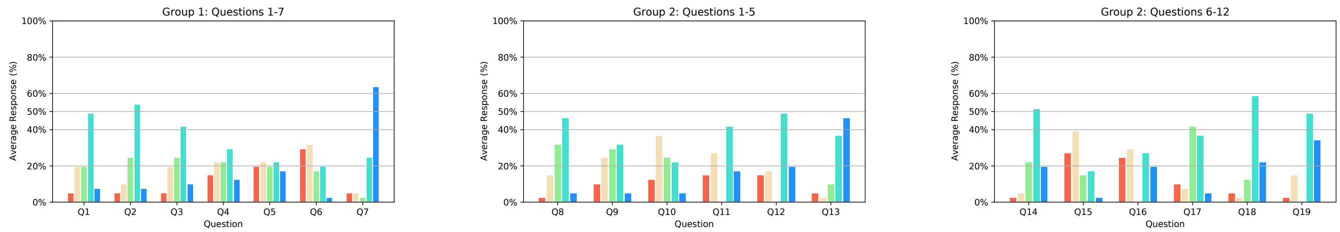
Research Goal	Question Group	Statement	
		1	Work in the lab helps me to improve my understanding of the theoretical concepts.
Goal 1: Adjusting teaching methods and material	Group 2	**2**	I can have my own learning pace in the lab.
		3	Lab reports help me organize my work on the project/practical assignments better.
		4	Polls during the labs help me resolve doubts about the project features and fill in the gaps in my knowledge.
		5	Participation in polls improves my general understanding of labs.
		6	I feel comfortable participating in polls although they are not anonymous.
		7	Work in the lab is flexible enough (I can work on the activities I have not finished yet).
		8	I made use of lab recordings to understand the matter in a better way.
		9	I would prefer to listen to lab recordings first, and then participate in discussions during labs.
		10	I think my feedback during the lab is taken into consideration to improve the lab quality.
		11	I feel comfortable to use online tool features to express my feedback during labs.
		12	No restrictions on accessing the lab resources helps me finish my tasks in time.
Goal 2: Enhancing students' knowledge and skills	**Group 1**	**1**	I am satisfied with the quality of the lab exercises.
		2	The lecture material is comprehensible for me.
		3	The lab exercise material is comprehensible for me.
		4	The quality of lectures is not negatively affected by online teaching.
		5	The quality of lab exercises is not negatively affected by online teaching.
		6	Lectures helped me understand the lab exercises better.
		7	English did not affect my understanding of the lectures/labs.
	Group 5	**1**	Breakout rooms facilitated my work with the team.
		2	My team and I worked together out of the scheduled hours as well.
		3	I think that collaboration in my team is on a satisfactory level.
		4	I think all my team members are equally involved in the work.
		5	I like working in a team on project/lab assignments.
	Group 6	**1**	How satisfied you are with the improvement of Programming, Networking technologies, Data analysis, Work with Linux, Virtualization, Work on the cloud, and System design.
		2	How much Programming, Networking technologies, Data analysis, Work with Linux, Virtualization, Work on the cloud, and System design, will help you in your future job.
Goal 3: Providing remotely accessible labs with no restrictions on access, and regardless of students' equipment at home	**Group 4**	**1**	Working on the testbed during labs helps gain practical knowledge.
		2	Working on the cloud during labs helps gain practical knowledge.
		3	Lack of graphical user interface in working on the cloud is not a limiting factor.
		4	I feel that I am working with tangible resources when I work on the testbed.
		5	I feel that I am working with tangible resources when I work on the cloud.
		6	Testbed is more complex to set up.
		7	I needed to improve my skills in working in Linux to be able to work on the testbed.
		8	I needed to improve my skills in working in Linux to be able to work on the cloud.
		9	After labs, I will feel more comfortable working on the testbed in the future.
		10	After labs, I will feel more comfortable working on the cloud in the future.
		11	After labs, I would prefer to work on my own computer in the future.
	Group 3	**1**	I do not need powerful equipment at home to participate in the labs.
		2	My internet connection is not a limiting factor in participating in labs.
		3	The physical absence of the instructor does not affect the lab quality.

students' preference over different experimentation environments, which can help decide on the suitable experimentation tools for the next students' generation.

- *Groups 5 and 6 - Team work & Skills*: Particularly important for achieving Goal 1. First, team work is an inseparable component of work in most of the modern ICT companies. Second, it is important to inspect students' evaluation of their own skills, and how much do they think that they are ready for the job market after finishing educational course, because results can support educators in finding the most suitable programming language or networking technology, which will support students towards becoming more competitive.

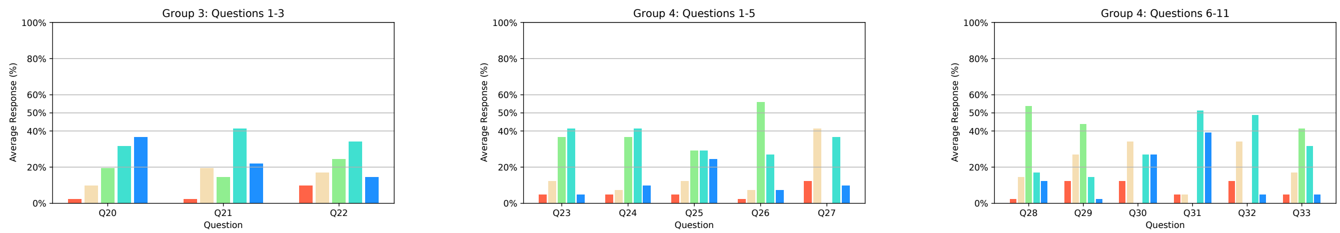
3.2 Results and Discussion

All responses corresponds to survey presented in Table 2. Concerning the Group 1 of survey questions, around 60% of students claim that they are satisfied with the quality of labs, lectures, and material prepared for both, as shown in Fig. 3a. Although students are not affected by teaching in English (i.e., around 85% claim to follow the course in English with no major issues), their opinion on the



(a) Group 1.
(b) Group 2 - part 1
(c) Group 2 - part 2

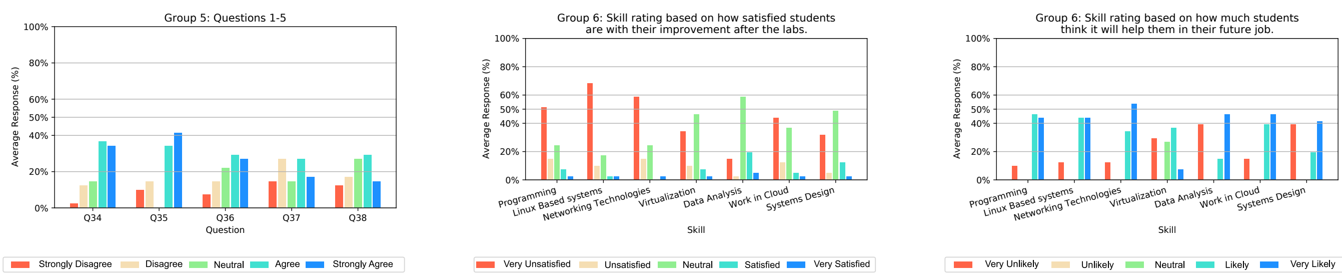
Figure 3: Responses to General quality of lectures and lab exercises (a) and Adaptive and personalized learning in labs (b and c)



(a) Group 3.

(b) Group 4 - part 1.
(c) Group 4 - part 2.

Figure 4: Responses to Flexible classroom environment (a) and Testbed vs. Cloud vs. Local (b and c)



(a) Team work.
(b) Skills - part 1.
(c) Skills - part 2.

Figure 5: Response to Team work (a), Satisfaction with improvement of the skills (b), and Evaluation of usefulness of gained skills for the job market (c)

online teaching is divided. In Question 4 shown in graph 3a (i.e., statement 4 in Table 2), around 40% claim that quality of lectures and labs is not affected by online teaching, while 20% is neutral. One interesting result is provided in question 6 (Fig. 3a), as it points at possible disbalance between lectures and labs, which might happen due to the organization of the course which first delivers lectures, and then starts with the practical exercises.

Furthermore, in Group 2 of survey questions, around 50% of responses show that labs helped students to improve their understanding of the theoretical concepts, while 30% of answers are neutral (Fig. 3b. As shown in Fig. 3b, we received an important feedback on the polls that we organized, as around 70% of students claim that polls helped to resolve doubts they had, and helped them to better understand lab material. Also, close to 70% of students claim they can flexibly work on the labs, as there are no time restrictions on access to resources, and close to 90% (3c) claim that flexibility helped them finish their tasks before the deadline. In addition, the response on the statement 2 in Group 5 shows that more than 70% students worked with their teammates out of the scheduled hours as well. Such results prove that flexible work in the laboratory, which is enabled by remote lab resources and adjustments in the labs, indeed helps students reach their targets in practical assignments. The result on the lab recordings in Fig. 3c is somewhat expected, where more than 60% of students claim they are not using lab recordings to improve the understanding of material. The reason for such result might be the time constraints as students spend most of the time working on the practical assignments in the project, and solving the issues they encounter. Such result also raises concerns about the flipped approach in other educational frameworks, where students first watch recordings and then proceed with discussion in live sessions, as it might not be the most suitable approach for most of the students. On the other hand, recordings help students who missed the class. The response to statements 10 and 11 in Group 2 (Fig. 3c) is also important, as it reflects on the adjustments that we make on-the-fly in the labs. More than 80% of our students comfortably use the online tool features to express their feedback during the lab (e.g., answering the question on whether is something clear enough, or is the explanation good, etc.), and around 40% confirm that their feedback is taken into account to adjust the lab, while around 50% of them are neutral.

Concerning the equipment students need at home, results in Fig. 4a show that no powerful equipment is needed, and no major internet connection limitations prevented students from working online. However, around 20% of students still think that labs lack physical presence of educators. Therefore, for the practical experimentation, a blended approach might be more suitable, which corresponds to some of the labs held online, while some discussion sessions should be held at the University campus.

The students' response on the questions from Group 4 (Figures 4b and 4c) reflects that most of the students consider working on the testbed and cloud as valuable for gaining useful skills. Concerning comparison between cloud and testbed, they are neutral when comparing the complexity of setting up the working nodes in both, but according to their response on the statements 9 and 10, around 90% feel more comfortable working on the testbed in the future after performing labs, and around 60% of them would also feel comfortable working on the cloud. As students sometimes might express restraint towards new working environments, we also asked them about their work on laptops. Only 40% will still rather stick to their own lab equipment when working on practical assignments.

According to results on the statements in Group 5, although most of the students consider breakout rooms in Blackboard Collaborate platform as useful for their work in teams, they have a divided opinion on the team work and distribution of the tasks among them. Therefore, there is a need for a peer evaluation in each group to assess the work done by individual students, and to also use this to motivate individuals to work more.

The feedback given for the Group 6 (Figures 5b and 5c) shows that majority of students consider they significantly improved their programming skills (around 70%), work on Linux (around 80%), networking technologies (around 65%), and work in the cloud (around 55%), which are the baseline skills our courses intend to build and improve. Such response is important as it also positively reflects on students' evaluation of usefulness of these skills for their future jobs as majority of them, as shown in Figures 5b and 5c, also claim that these skills will help them find jobs.

4 CONCLUSION

In this paper, we presented an adaptive and on-demand education framework for teaching engineering students remotely, thereby allowing them to perform experimentation in real-life testbed and cloud environments. We presented the process of adjusting this educational framework based on the i) formative assessment during labs, which enables adjustments of practical exercises and tasks, and ii) thorough feedback from students, including the insights from state-of-the-art technologies in industry and research. Based on the insightful feedback we collected from our students in two academic courses, we can see that flexible work in the laboratory, enabled by remote lab resources and adjustments in lab content, facilitates work on the project assignments, and helps students to enhance their skills. Although no specialized equipment is needed to perform labs from home, some of the students still consider that labs are affected by educators' physical absence, which leads to conclusion that a possible blended approach for labs might be a convenient solution for students. As our ultimate goal is to enhance students' knowledge and equip them with competitive skills, our results show that students consider they significantly improved the baseline skills our courses tend to build and improve towards preparing students' for the future jobs.

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