iLab@Home: Hands-On Networking Classes without Lab Access

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ABSTRACT

In 2020, the COVID-19 outspread changed university education overnight. Presence-teaching become impossible around the globe. Video-conferencing and collaboration tools enable a relatively straight forward transition of many teaching formats. Particularly difficult cases are hands-on lab courses, where students regularly come into a special university lab environment to do controlled experiments.

At TUM we run a laboratory for educating students with reproducible networking and distributed systems experiments on-site since 2003. This paper shows our two different paths towards fully-remote reproducible experimentation. It discusses advantages and drawbacks of the changed formats, introduces our virtualization for networking lab settings, and shows open issues we plan to solve based on our new experience. A quantitative evaluation shows differences from before to during COVID-19 teaching in the two different new implementations of our lab course series.

1 INTRODUCTION

Hands-on lab courses are an important element of higher education. They significantly foster active learning [5]. A core element of a lab course is a hands-on part. Hands-ons often happen within a controlled environment with special equipment. Such lab rooms are typically located on-campus.

With the hit of COVID-19 in 2020, in many countries students were not allowed to come on premises from one day to another. Utilities for video conferencing such as Zoom can successfully cover many aspects of a lecture setting: people can hear and see each-other, slides can be shown, synchronous interactions are possible. Even group-work is possible.

In some aspects, online lectures even outperform classical lectures, such as visibility of shown material, and quality of the audio arriving at each individual student. Also, the built-in possibility for interaction, for example with quizzes, can help making lectures more appealing. Such interactive elements were possible in on-site lectures before the change to purely-online.

However, tools such as tweedback [16] require special effort from the teachers for introducing them in class, and - most importantly - result in a distressing switch of interaction mode due to the break of the medium [13]: from attentively following class to briefly working on the smartphone, laptop, or other digital input device - with all other distress items on these devices.

Regarding the regular use of digital tools for teaching, COVID-19 is driving the Digital Transformation in class. The described developments would probably have taken many years in other circumstances.

Still, standard tools such as videoconferencing cannot cover all elements of on-premise teaching. Settings that are especially hard to replace with purely-online formats are hands-on experiments.

This paper reports about the experiences when transforming the so-called iLab hands-on lab courses running at Technical University of Munich into fully-distant teaching due to COVID-19.

Section 2 introduces the didactical concept behind all mentioned lab courses. Section 3 describes how the different elements of the courses were transformed to fully-distant. Section 4 evaluates the effects on the learners of the two different format we implemented quantitatively. Finally, the conclusion discusses lessons learned and next steps (section 5).

2 THE ILAB CONCEPT

The hands-on lab courses we use as setting in this paper run at three universities: Technical University of Munich, University of Tübingen, and University of Sydney. There are six lab courses running each term with the teaching methodology introduced next: the *iLab concept* [12].

Each term the four on-site blended learning courses teach more than 100 students. Overall more than 3000 students participated so far. In 2019, we launched a Massive Open Online Course (MOOC) based on the iLab concept on edX, "iLabX - The Internet Masterclass," [8]. More than 1500 students participated in iLabX during its first run.

Common to all previously mentioned courses is their structuring into 6-10 modules that the students follow sequentially. Each module goes through the phases I-IV in table 1. The typical timeframe for one module is one week.

For our computer networks and distributed systems education we use and continuously refine a blended-learning

	Name	Setting	Place	Time
I	Lecture	Group	Lecture Hall	2h
II	Preparation	Individual	Anywhere	4-6h
III	Hands-On	Team	University Lab	6-8h
IV	Oral Exam	Individual	University	30min

Table 1: Elements of the iLab concept [12].

methodology called the *iLab concept* [12]. The iLab concept consists of the four parts shown in table 1: I. Lecture, II. Preparation, III. Hands-on, IV. Oral Exam.

The four elements from table 1 have different goals. The goal of the *group lecture* (I) is explaining the context and fundamentals of the upcoming module. It also serves for stimulating group discussions on the topics covered so far.

The *individual self-learning block* (II) targets an individual preparation of each student. It happens online within a self-developed open-source eLearning environment, the labsystem[11]. This part helps deep-diving into a topic. Another major goal is preparing all team mates individually to reach a similar knowledge, enabling a successful collaboration in part III.

The main part is the *hands-on* (III). In regular times, this happens on-site in our specially outfitted lab room. The hands-on is done in teams of two with the support of the labsystem eLearning environment. The labsystem contains the instructions and collects the experimentation results.

A team size of two is ideal for supporting each other on the one hand, and having both collaborators involved on the other. The goal of the hands-on is getting a first-hand lab experience. The active working with the hardware and software stimulates the learning process. In the iLabs, the students solve challenging real-world problems such as setting up dynamic routing using the Open Shortest Path First (OSPF) routing protocol.

The last part of the iLab concept is the *Oral Exam* (IV). The oral exam happens individually on-site. Its learning-support goal is forcing the students to look at the content once again. In addition, they get a learning success control. Finally, it is an important part for the grading together with the credits the teams get in the hands-on (III) [12].

3 TRANSFORMATION TO FULLY-DISTANT TEACHING

The different parts of the iLab concept (section 2) were affected differently through the COVID-19-caused stop of students coming on campus.

This section reports about the strategies and experiences with transforming the iLab concept into fully-distant learning. It is divided into two parts, the easy-to-transform elements ~section 3.1 and the hard-to-transform parts (section 3.2).

3.1 The *easy* parts

A big advantage when transforming the iLab concept to purely virtual is that it always was a blended-learning course, combining online and offline elements. With more than 17 years of successful eLearning experience, many pitfalls were already known and many best practices were already in our repertoire when starting the process.

Our approach for the easy parts of the transformation to purely-distant learning is replacing the university building with an online group video conferencing tool Following the university strategy, our choice was Big Blue Button (BBB) [2]. As key features, the tool offers video conferencing, slide sharing with annotations, and a shared notepad.

For the *I. Lecture* we keep the fixed hours. The students dial-in from home. We check the mandatory attendance. It works fine.

For the lecture the new online format brings the advantage that students can use the chat for interaction during the presentation. This even increased the interaction compared to the classroom setting. Students seem to feel less hurdles for interacting.

A clear drawback is that the group feeling does not occur that much. In the classroom, there is always a momentum motivating the students. Online, each student has to motivate herself. To cover this partially, we motivate the students to voluntarily open their cameras. This showed positive results for motivating each other.

Another drawback is that the students do not discuss after class, which they do in the on-site format. Technically it would be possible online as well. But it requires more effort - especially regarding coordination by the individuals. So, it does not happen. Since such discussions are often on-topic, this probably reduces the learning effect.

Figure 1 shows a typical teacher setup. The laptop on the left and the big screen are used for the slide presentation. They are equivalent to the projection in a regular classroom.

The iPad on the right is logged in to BBB independently. It serves as a control monitor: it shows what the students really see. Monitoring the participant's view came in handy several times already, as there were apparently problems on the tooling, such as screen-shares suddenly stopping to work. In addition, the monitoring post helps the teacher to get a feeling of talking to an audience class since in the used setup, in BBB one does not see the audience anymore when presenting.

Regarding the Individual Preparation (II. in table 1), there is no change to before. The students individually go through the online material in the labsystem eLearning environment. Interaction happens via tickets and mails [12].

For the *Oral Attestation* (IV. in table 1)) we also started using Big Blue Button. Students have to show their hands

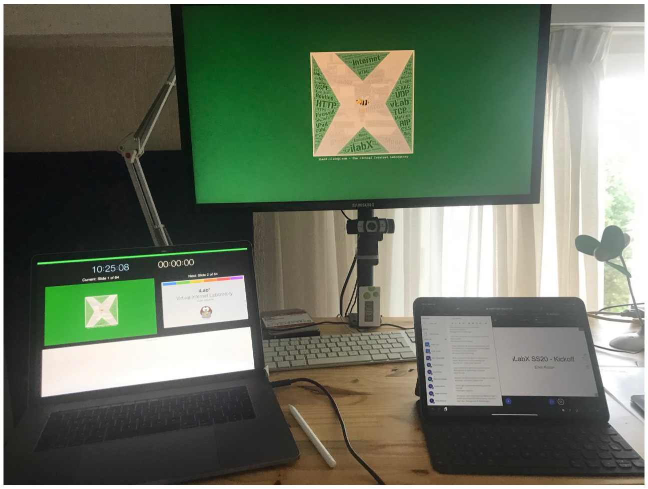

Figure 1: Distant teaching setting with presentation and control client via pad.

and are not allowed to use earplugs. Through the nature of our exams, being individual discussions that focus rather on understanding than on knowledge, this seems to go quite well. The performance of the students is comparable to on-site exams.

3.2 The *hard* part(s)

The hard part to transform to purely-distant learning is the *Hands-on* (III in table 1)). For our experiments we have so called iLab isles in our specially equipped laboratory room. We have six isles, allowing 12 students to work in parallel in teams of 2.

Each iLab isle consists of four PCs with five network interfaces each. In addition, we have two Cisco routers per isle, two Gigabit switches, 2 keyboard-video-monitor (KVM) switches, and finally two monitors, keyboards and mice. Everything is tailored for two people collaborating on our exercises that are designed for exactly this setup [12].

The isles are isolated via vlans. Each PC runs a Debian with a read-only filesystem, ensuring a reproducible state for each isle on reboot. This is crucial for having fair, reproducible results of the controlled experiments. Figure 2 shows one iLab isle in the background.

With the closing of the university building, the lab room was not available for students anymore. However, through the wide deployment of course instances across multiple universities, we were in a comfortable situation of having experience with different settings already.

The team in Tübingen around Christian Hoehne, Michal Menth, Joachim Schiele, and Mark Schmidt had decided to virtualize the isles partially already earlier. Their goal was reducing hardware costs [15].

In Munich we explicitly did not want to do this to give the students the full cabling-experience [12]. For Sydney, a fully-virtualized solution was used. We originally developed it in Munich for the edX MOOC "iLabX - The Internet Masterclass" [8].

The virtualized version of the physical iLab isle is called vLab (virtualized lab). The vLab is an open source [10] virtual box image that can be started within the corresponding virtualization environment. The image contains a Debian that is very similar to the installations at the physical iLab isles. We did this on purpose for having a similar look and feel and the opportunity to potentially shift to fully-virtual for some of our regular exercises.

A goal when creating the vLab was using as little resources on the host of the virtual machine as possible. This is important to enable students with different hardware resources to successfully do the experimentation.

At the same time, it was important to have an experience as close to the physical iLab isles as possible. For both reasons, our tool of choice was the Common Open Research Emulator (CORE) [14]. CORE offers a lightweight virtualization. Basically, a read-only file-system copy of the hosting system is used for each virtual machine while execution resources are shared with the hosting system. In our case, the hosting container is the virtual box image, resulting in virtualization within a virtualized container.

Regarding the similar look and feel, CORE offers a graphical interface. Entities such as computers, routers, and switches are visualized as symbols fig. 2. Network cables can be wired by drawing lines between interfaces. Though this still misses the "touching a real cable", the experience is as close as it can get to a real iLab isle. Figure 2 shows the running vLab container with the CORE instance of an iLab isle. The setup in the foreground is the virtual implementation of a physical iLab isle.

CORE cannot emulate a Cisco router running IOS. This is a problem since the exercises of our courses iLab1[6], iLab2[7], and iLabX[9] rely on-purpose on Cisco routers. We want to teach the students using dedicated hardware with own operating systems.

Consequently, for making the iLabs fully-distant, we saw two options: (1) Pre-cabling of the physical iLab isles and giving the students remote access, and (2) Switching to the vLab and having to deal with the missing Cisco routers. As we have three courses, we decided to test both.

For the iLab1, the team around Lars Wüstrich and Dominik Scholz did a fantastic job in updating the lab room so that the endeavor became possible. For each iLab module, the isles are pre-cabled. Students get access as if they would physically come to the room [12] - only remote. This scheme allows teamwork since both students can log on to the experimentation platform.

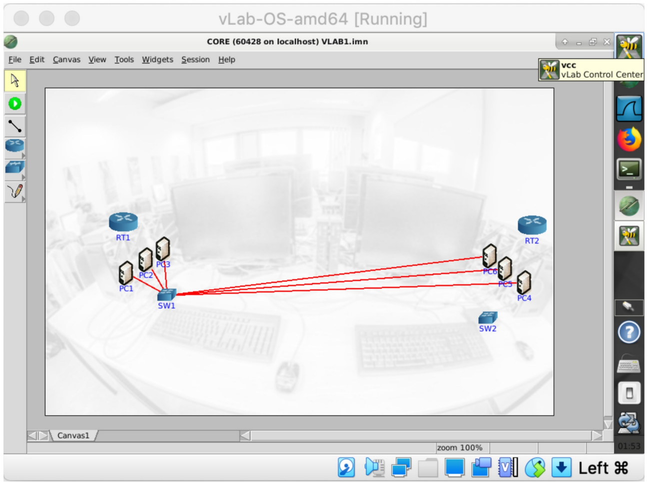

Figure 2: The vLab virtual iLab isle.

For the iLab2, the team around Christian Lübben and Erkin Kirdan went through our set of exercises to identify those that do not rely on Cisco routers and can therefore be run directly on the vLab. As described before, most regular iLab2 exercises involve the Cisco routers for including this experience. To mitigate from the Cisco-router-problem, another course concept from the iLab2, "Create your own Lab," came in handy [13].

In the "Create your own Lab" part of the iLab2, students continuously create new small exercises around a focus topic we set [13]. This results in a continuously growing pool of exercises. Though the didactical concept of this part already ensures a high quality of these exercises, we typically have to invest additional work to make them run in future editions of the iLab2 course. In regular runs, we give the students a set of these so-called minilabs as choices to select two that are then done as one part of the course.

For the Corona-Run of the iLab2, the set of exercises was changed. Similar to the iLabX [9], the first part became the iLabX MOOC [8]. For the next exercises, regular content was replaced by suitable minilabs. Only the regular WWW Security exercise remained as it does not require a Cisco router. Finally, the students are currently creating own exercises.

The vLab-based iLab2 also went well. Through the iLabX and the edX MOOC we already had extensive tutorials for getting the vLab running on the student's hosts.

For the second part though, establishing real collaboration between the students was difficult. A certain collaboration was necessary since the labsystem only allows team answers. Consequently, both team partners either had to work together on the formulations, or trust each other and share the load by that.

4 EVALUATION

An important part of the iLab concept is feedback [12]. A continuous qualitative and quantitative evaluation accompanies the course runs, giving us a good monitoring of the learning progress and success of our students.

From the oral attestations so far, the students reached the learning goals. For the iLab1, the learning experience is very close to before the fully-distant setting at the cost of additional effort on our side for the cabling and problem-handling, e.g. by rebooting machines.

For the iLab2, the experience is different from earlier runs. The exercise set is different as well as the implementation with having the MOOC as a start. Still, the changed learning goals were well-reached.

In the following, we look at the quantitative evaluation of the student performance within the labsystem environment. For that, we use the grading results from the manual corrections and the time trackings through the labsystem. Both are averaged over all teams.

For the gradings we have detailed grading schemes within the labsystem [11]. The explicit schemes assure correction quality. As a side-result, the clear grading rules enable comparing corrections and gradings over time.

For the time measurements, the labsystem logs every interaction with the website. For the practical part, the times of both students get added-up.

The time tracking is purely passive, meaning that the mechanism does not check if the students are really actively working or surfing around other issues, pausing, or eating. If entire cohorts suddenly have a different behavior to before, this cannot be detected by the time tracker.

This results in an overestimation: in case both students work in parallel at the same time, these times are counted double. However, as the algorithm is always the same, the time tracking gives a good comparative analysis between student cohorts.

In our regarded run summer term 2020, we changed the setups as described. Therefore, it is interesting to look at how the parameters evolved. In the following, we look at:

- iLab1: remote access to the physical isles (fig. 3)
- iLab2: fully virtualized (fig. 4)

In both cases we compare the last 4 runs on a representative exercise. For iLab we chose Dynamic Routing. For iLab2 we chose WWW Security.

Figures 3 and 4 show the graphical representations of the results. The x-axis are the achieved and achievable credits. The y-axis is the time on the left and each question to answer as milestone on the right.

The gray form shows the performance of a team that would always get full credits. This projection helps to see if the credits per time are well distributed, or if there are

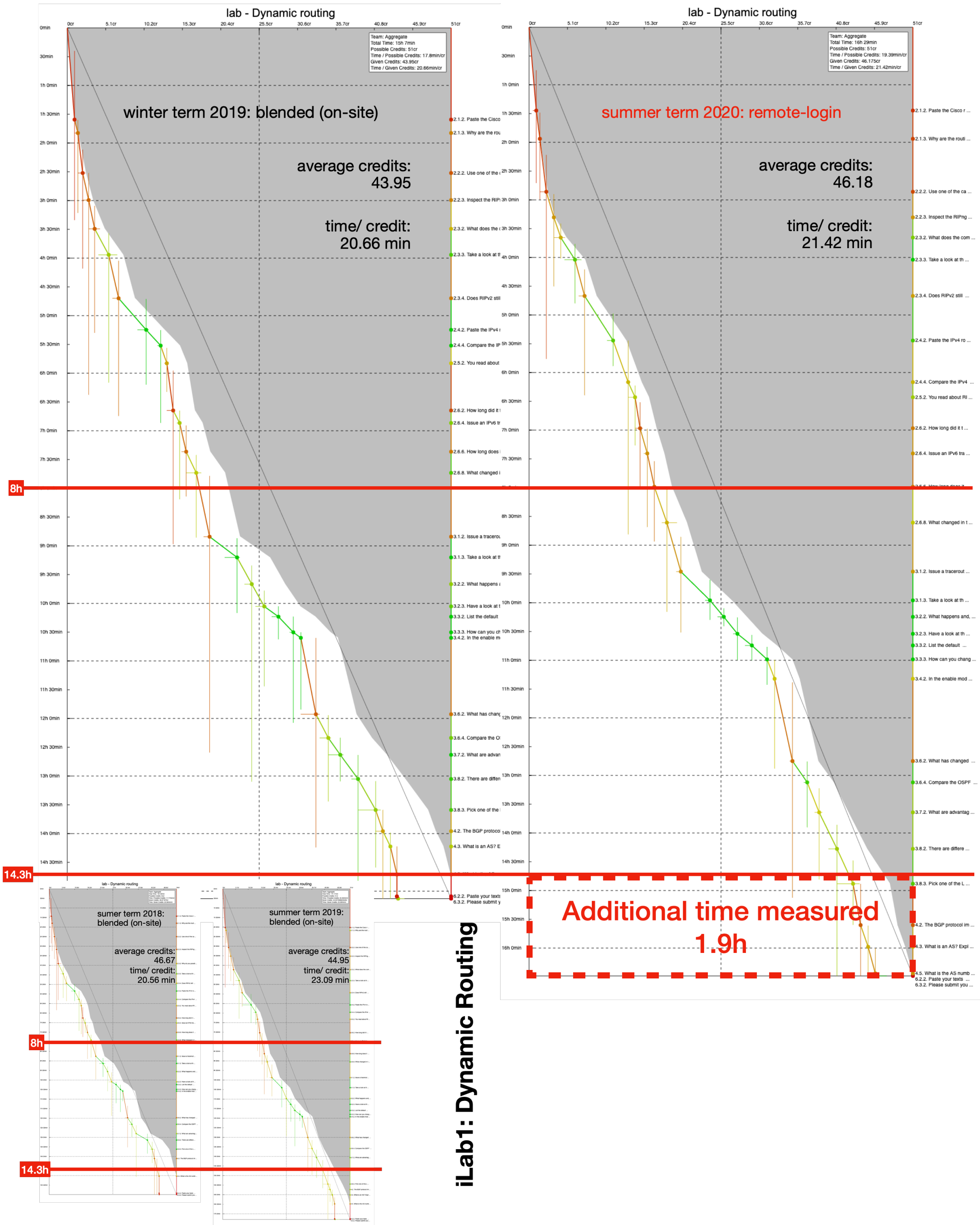

Figure 3: Time tracking iLab1 Dynamic Routing exercise in regular settings "winter term 2019" on the top left and the current virtual setting "summer term 2020" on the right. Bottom left are the terms summer 2018 (left) and summer 2019 (right) for comparison. Time and credits of the remote-connection setting are comparable to on-site.

tasks that take especially long while giving little credits. The straight gray line from the origin to the right bottom indicates the equal distribution: $\frac{\text{overall time}}{\text{overall credits}}$ time per credit. It is neither realistic nor desired to reach this line.

The colored line on the left of the gray form shows the actual student performance. The solid line of connected point is the average over credits and time at each question. The "antennas" show the variance of the values from the lowest to the highest credits (x-axis), and the fastest to the slowest team (y-axis).

The line is color-coded. Green means that the teams are faster than the equal distribution in this part. The more it goes into red, the slower they are compared to the equal distribution.

The graph on the top right shows the results of the current term. Left to it is the last term. On the bottom left are two other comparison terms to indicate an expected baseline.

4.1 iLab1 interpretation: remote-connection

Figure 3 shows that regarding both, credits and time, the remote-login mode is comparable to when the students were able to visit our university laboratory. This is what we expected as the experience is very similar.

The average credits are 46.18 compared to 43.95 (2019wss), 44.95 (2019ss), 46.67 (2018ss). The average time per credit is 21.42 compared to 20.66 (2019ws), 23.09 (2019ss), 20.56 (2018ss). The variance of the values is comparable to past on-site runs. Note that we did not put 2018 winter term but summer term here for the sole reason that the winter term had some drop outs in this lab that pull the numbers as outliers down.

Through the remote-login on the prepared isle, the students gain some time as they do not have to do the cabling. At the same time, they have some overhead as they have to synchronize with their team partners over distance.

The additional time of 1.9h shown on the right comes probably from the distant collaboration where the partners are a bit less in sync and therefore more likely to do things in parallel that count double then. This overhead is comparable to 2019ss. Therefore, it can also simply indicate a difference in the performance of the cohort. Since the students got more credit, they might have looked at the content more or worked on their answers more carefully.

4.2 iLab2 interpretation: fully-virtualized

Figure 4 shows the graphs for the iLab2 exercise WWW Security. Here we see a similar result in the grading. The average credits are 55.46 compared to 57.72 (2019wss), 56.63 (2019ss), 53.9 (2018ws).

Regarding the time, the current fully-virtual run reports significantly (~50%) more time investment. It is obvious that the current fully-online term reports more time for the same content. Winter term 2019 in the regular on-site run the overall average time was 12h25. Summer term 2020 in the fully-online run the overall average time was 17h25.

The average time per credit is 18.85 compared to 12.92 (2019ws), 14.46 (2019ss), 9.21 (2018ws). This can have different reasons:

It could be that the students had more difficulties in implementing the exercise with the vLab compared to doing so in an iLab isle. Since the students did the iLabX edX MOOC before, this is unlikely.

The 5.5.h extra time could indicate that the students had significant overhead through not having a common testbed to log on. As both students had to do the entire setups on their own - though being virtually connected - this will likely play into this time. The significantly higher variance in time supports this interpretation.

As described before, the labsystem overestimates the time used. When both students work from their places, this likely causes additional measurement overestimation. More concrete, the two students will in parallel look at material and not together as they would typically do in the lab room where they sit next to each other. This results in more recorded activity time.

For the WWW Security the students need a special virtual machine (VM). At the beginning there were some problems getting this VM running. This took the teams some time, definitely also contributing to the higher overall time.

5 CONCLUSION

With the multiple iLabs we had the chance to try different models for going fully-remote.

The iLab1 did that well by providing the cabled isles for collaboration. However, this brought overhead and limited value compared to if we had a full emulation of an iLab isle.

In fact, from a learning perspective pre-cabling is worse than a local emulation with graphical interface as the students do not see or have influence on the cabling. Correct cabling however is one of the learning goals of the networking course. Cabling errors are also important to make and learn from.

With the switch to fully virtual in the iLab2 we lost relevant learning content. Changing the existing content to fit for the CORE emulation without Cisco routers would have been too time-consuming. Also we expect to switch back to regular soon again.

In the meantime, we know that GNS3 [3] should support Cisco IOS. Therefore, we are about to integrate GNS3 to the vLab [10]. We expect the regular iLab exercises to work in the vLab then. This would allow running all original iLab exercises within a virtualized container. The only issues that we anticipate for such a setting is timing issues for measurements. Some results might not be comparable due to different hardware at the disposal of different students.

The iLab concept has team work as central concept for several reasons, including that working on and discussing a problem with someone else is much more stimulating the learning, often faster, and simply more fun [12]. All three increase the learning [5].

A major drawback of fully-remote collaboration is however that it takes effort to collaborate in a team. As another update for the vLab we therefore plan to integrate simpler collaboration tools for video and audio connection with the team partner. A one-click access to a *public video conference server* like JITSI [4] seems to be a good option for that.

Similarly, we plan to enable secure remote-login into the locally running vLab VM. Both would allow much better teamwork as the team partners could see and hear each other and see the same experimentation space at the sames time. The emulation of the lab room would be much better then. As tooling we plan to look at TightVNC [1].

Enhancing the collaboration would also be good regarding the group as a whole. Part of the iLab concept is that the teams present in the lab room support each other. This helps both, the helpers that learn about new problems and can exercise debugging more, and those asking for help as they can learn from their fellows [12].

A *support forum* could be a good option here but we are not sure which solution to follow yet. The biggest problem we see is that the synchronous helping might be difficult due to students working on the exercises at different times.

Overall, COVID-19 also sped up activities in the iLabs. Testing exercises for suitability in the vLab was on our agenda for longer but we did not take the time before.

Regarding the learning outcome, we expect it to be similar to on-site regarding the covered aspects. Factors like teamwork and physical touch as well as the Cisco IOS knowledge will remain missing by now.

Our overall conclusion is that fully-distant virtualized networking education with hands-on is possible. This is why we also created the “iLabX - The Internet Masterclass” edX MOOC [8]. However, it misses important factors.

We expect to cover the Cisco IOS topic by adding GNS3 to the vLab. We plan to add a one click collaboration to the vLab regarding audio and video sharing, and working on the same lab space.

Creating a real group feeling with all aspects such as peer-motivation coming from it will still be hard.

We invite and recommend other teachers to use our virtualized vLab experimentation isle [10]. It helps having a virtualized hands-on experience that is to our experience the closest it can get to real physical hands-on in networking.

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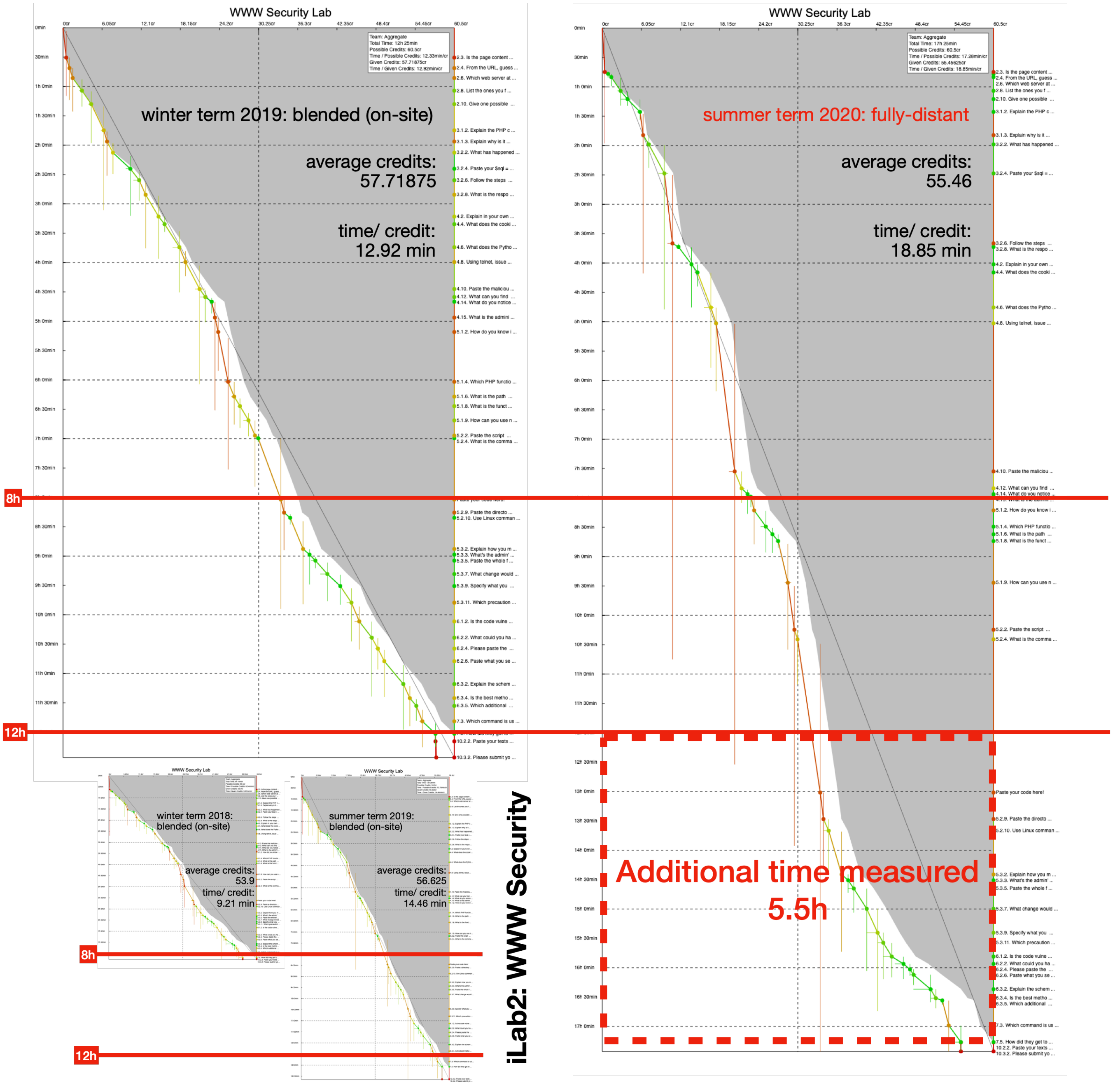

Figure 4: Time tracking iLab2 WWW Security exercise in regular settings "winter term 2019" on the top left and the current virtual setting "summer term 2020" on the right. Bottom left are the terms winter 2018 (left) and summer 2019 (right) for comparison. A clear additional time for the fully-virtual is visible compared to on-site.