Teaching “How the Internet works”, remotely but still hands-on

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I usually start my lecture on “Communication Networks” by telling students that at least one major Internet-related event—one which is directly relevant to the lecture—will happen over the course of the Spring semester. Thus far, I was never wrong.

In April 2017, traffic from Visa, MasterCard, and Symantec (among others) got (incorrectly) rerouted through a Russian network [1]. In February 2018, GitHub sustained what is still the largest DDoS known to date (1.3 Tbps) and mitigated it using BGP rerouting [4]. In June 2019, a Swiss data center mistakenly leaked over 70,000 BGP routes to one of its Chinese peers, causing a large chunk of the European mobile traffic to transit for two hours through China [3].

This year, my prophecy proved to be right, once again. As I started lecturing in mid-February 2020 though, far was I from knowing the magnitude of the events to come only a couple of weeks later—and the importance the Internet infrastructure will play.

Our lecture, in a nutshell. Our undergraduate lecture teaches how the Internet works to third-year Bachelor students in the span of 14 weeks. Instead of following a “classical” top-down or bottom-up approach, our lecture starts “in the middle of the stack”, following the philosophy of Scott Shenker, focusing first on the fundamental problems solved by networks before describing any actual technology (i.e., before bashing the students with three/four letter acronyms). In case you wonder, the two fundamental problems we cover pertain to: routing (“How do we guide packets from a source to a destination?”) and reliable delivery (“How do we ensure reliable transport on top of a best-effort infrastructure?”).

Besides this slightly unusual organization, what truly distinguishes our lecture is its hands-on approach. More specifically, our lecture includes two practical projects: (i) a class-wide “build your own Internet” project; and (ii) a “implement your own reliable transport protocol” project.

The mini-Internet project is the highlight of our lecture. It consists of having teams of students operate their very own Autonomous Network (AS), composed of around 10 IP routers, that are interconnected together to form an actual Internet. ASES peer with each other directly or through Internet eXchange Points (that we, the instructors, maintain)—just like in the real Internet. The goal of the students is to enable any-to-any connectivity across the entire Internet using the technologies seen in the lecture including VLANs, OSPF, and BGP. This year we had 150 students working together on the project—a record number for us.

The switch to online. Due to COVID-19, we had to switch the entire lecture online after only four weeks, on short-notice, and before any of the projects actually started. (We started the mini-Internet project during the first week of the confinement). As for any instructor out there, this was quite a process. Yet, I think it worked well for us. And our satisfaction survey revealed that the students particularly appreciated the lecture which was not a done deal. In the following, I reflect on a few key aspects which (I believe) made the lecture work and the challenges we encountered along the way.

Class-wide projects helped to maintain a classroom feeling. While convenient, online learning is often a lonely experience where the feeling of belonging to a class is lost or diminished. I believe having a class-wide project such as our mini-Internet really helped minimizing this effect. Such project indeed creates a common goal that all students, together, have to work towards. In particular, the very nature of the project—having students’ networks transit each other traffic—mandates class-wide communication and, more often than not, class-wide debugging. Clearly seeing the network “come to live” is empowering.

Surprisingly to us, the project worked even better online. Our students indeed managed to achieve complete connectivity between each other, a first for us since we teach the class. And this is despite the fact that we had a record high number of students attending the lecture (+50% with respect to last year).

While I would like to encourage every instructor out there to try out such class-wide assignments, I must say that they also come at a relatively high cost in terms of support. We are lucky enough at ETH Zurich to have a large team of teaching assistants who are, to top it off, passionate about teaching. That said, I believe one does not necessarily need the sophistication of the mini-Internet project to bring an entire classroom together. Among others, class-wide challenges come to mind in which students could, say, compete on minimize downloading times (e.g. by adapting congestion control parameters in a virtual environment). While these projects still bring the classroom together, they create less dependencies amongst students, and therefore are easier to manage overall.

Asking students feedback, and acting upon it. Switching an entire lecture to online-only involves making a lot of decisions “in the dark”, i.e. without knowing their actual implications. This is especially true if it is the first time, and if done on (very) short notice, as it was in our case. As such, it is key to ask students feedback and act on that feedback, even if that requires adapting once more the entire workflow, as it happened to us.

Four weeks into the confinement, we circulated a survey amongst our students asking them to comment on the (online) course organization and what they would like us to improve. This feedback helped us identify a few dark spots in our offerings, namely in the way: (i) we were lecturing; (ii) we were interacting with the students. In both cases, the students asked for more “in-person” interactions.

1The materials for our lecture are online on https://comm-net.ethz.ch.

2If you are interested in learning more about the project, we recently wrote an ACM SIGCOMM CCR paper on it [1]. We also open-sourced the entire platform which can be accessed online: http://mini-internet.

3We are currently developing such a challenge for our master-level lecture. We intend to release the challenge publicly, as we did for the mini-Internet.
Regarding lecturing, we initially decided to rely on previous years’ video recordings (slides + audio). In the survey though, the students pointed out to us that these recordings were suboptimal since: (i) they were rather impersonal (there was no “human” to be seen); (ii) they did not include the laser pointer, making it hard for them to follow what was referred to during the lecture; and (iii) they did not allow them to actively participate. After this feedback, we decided to switch to online “live lecturing”. We still recorded the sessions for students who could not make it for the live session.

Regarding interactions, we initially interacted with the students mostly via chat (using one of the popular tools). Students rightly pointed out though that chat-based communication is limited as: (i) asking (and answering) longer questions is cumbersome; (ii) interactions can be misinterpreted as they lack the nuances of voice tone or body language. Following this feedback, we therefore offered the students additionally office hours to interact with us via voice and video chat.

While these adaptations were simple, the students were pleased with them—most importantly, they were pleased to have been heard.

**Keeping the students engaged with the materials.** There is no denying that the Internet played a key role in the pandemic, enabling us to: stay in touch with our relatives, work remotely, stay informed, and stay “entertained”. The sudden increased dependency on connectivity raised numerous questions about the ability of the Internet infrastructure to cope with this extra load. These questions led to many interesting news that we could share and debate with our students. One example was the decision of Netflix to cut streaming quality in Europe to “spare bandwidth” [5] and the need for such measures. While the flow of information mostly came from us at the beginning, the students quickly started to share relevant articles themselves and commented on them.

Again, while looking for such articles and debating them is time-consuming, doing so definitely helped illustrating the relevance of the lecture concepts.

**All this said, online teaching is not a panacea.** Switching to online lecturing was not “all roses” though—be it for me (the instructor), the students, or the teaching assistants.

As an instructor, what I really found hard is the lack of immediate feedback that comes with in-class lecturing. Among others, one quickly realizes when the pace is too fast/slow and can adapt accordingly. Online lecturing does not enable such things. Also, while online platforms do enable to ask questions live, few students do so and instead prefer to ask questions out-of-band, after the lecture, thereby increasing the load on the teaching assistants.

For our students, organizing their group logistics was often way harder, especially as quite a few of our students flew back to their home countries, possibly in different timezones.

For the teaching assistants, the load this year considerably increased as it became harder to address questions “in bulk”, e.g. by simply addressing the entire classroom during an exercise session.

**Closing thoughts.** “Given the circumstances”, our switch to online lecturing ended up being successful. In doing so, we discovered that projects, class-wide projects in particular, were key in keeping the spirit alive. We also realized that organizing student feedback rounds was a crucial and invaluable element to guide our decisions. We also realized firsthand that there are certain elements of in-person nonverbal communication that today’s technologies just cannot emulate. *I look forward to teaching in a classroom again!*

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**REFERENCES**


