Challenges and Opportunities in Synchronous Online Teaching

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Abstract

Online teaching at higher educational institutions has become a much higher priority in the face of the COVID-19 pandemic, but most faculty and staff at these institutions are ill-prepared to adapt their teaching methods and content to this new medium. In this article, we describe our approach to dealing with the challenges and opportunities of synchronous online teaching by borrowing ideas and tools from the gaming community. The gamification of education is a well-known concept, but we found few applications in higher-education settings to rely on when we were forced to move online in March 2020. We hope to remedy this gap by providing colleagues with a step-by-step guide to setting up their own home studios, including a complete listing of the software and hardware that we use and how we use them in three distinct online teaching applications: a large (90-student) graduate healthcare finance course at MIT, an even larger (200-student) undergraduate statistics course at the University of Tennessee Knoxville, and a medium-sized (50-student) graduate operations management course at MIT.

Keywords: online teaching, distance learning, live streaming, MOOC, gamefication

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## Contents

1. Introduction .................................................................................................................. 1
2. Teaching Philosophy ..................................................................................................... 1
   2.1. Why In-Person Is Better Than Online ..................................................................... 1
   2.2. What Gamers Can Teach Teachers ........................................................................ 1
   2.3. How Online Technology Can Facilitate Learning .................................................. 3
   2.4. Tour Guide vs. User’s Guide .................................................................................. 4
3. Our Home Studios and Online Teaching Formats .......................................................... 5
   3.1. Andrew Lo’s Home Studio ..................................................................................... 7
   3.2. Brian Stevens’ Home Studio .................................................................................. 8
   3.3. Sean Willems’ Home Studio .................................................................................. 9
   3.4. The Trials and Tribulations of New Technology ...................................................... 10
4. 15.482 Healthcare Finance at MIT (Andrew Lo) ........................................................... 10
   4.1. The Challenge and Course Objectives .................................................................... 11
   4.2. Course Design ....................................................................................................... 12
   4.3. Before and During Class ...................................................................................... 13
   4.4. Guest Speakers ..................................................................................................... 20
   4.5. After Class ............................................................................................................. 21
   4.6. Outside of Class ..................................................................................................... 22
   4.7. Practicum ............................................................................................................... 23
   4.8. Did It Work? .......................................................................................................... 24
   4.9. Lessons Learned .................................................................................................... 26
5. Statistics 201 at the University of Tennessee (Brian Stevens) ........................................ 28
   5.1. The Challenge and Course Objectives .................................................................... 29
   5.2. Course Design ....................................................................................................... 31
   5.3. Before and During Class ...................................................................................... 32
   5.4. After and Outside of Class .................................................................................... 35
   5.5. Lessons Learned .................................................................................................... 36
6. 15.761 Introduction to Operations Management at MIT (Sean Willems) ....................... 38
   6.1. Studio Design Criteria ........................................................................................... 40
   6.2. Course Structure .................................................................................................... 40
   6.3. Lessons Learned .................................................................................................... 44
   6.4. Did It Work? .......................................................................................................... 46
7. Conclusion ...................................................................................................................... 47
A1 Hardware ....................................................................................................................... 1
A2 Software ......................................................................................................................... 7
A3 Equipment List (Andrew Lo’s Studio) .......................................................................... 12
A4 Equipment List (Brian Stevens’ Studio) ....................................................................... 13
A5 Equipment List (Sean Willem’s Studio) ....................................................................... 14
A6 Useful Links to Online Resources ................................................................................ 15
A7 Sample Zoom Chat Window Transcript from 15.482 .................................................. 16
A8 15.482 Fall 2020 After-Class Evaluation (implemented in Qualtrics) .......................... 17
References ......................................................................................................................... 18

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1. Introduction

During the second week of March 2020, we were informed—along with most of our academic colleagues—that all of our classes were moving online immediately in response to the growing impact of COVID-19 in the US. Although clearly the right decision at the time, the switch to online-only lectures was quite a shock for two of us (Brian has been teaching online for years, so he was well prepared). Despite having developed a considerable amount of online material in the form of massive open online courses (MOOCs), we (Andrew and Sean) had no experience delivering synchronous lectures or producing our own videos. In fact, we relied on the very capable services of various video production crews at MIT and the University of Tennessee, Knoxville.

So when the pandemic hit and we moved online, the three of us had very different experiences during the second half of the Spring 2020 semester. While the Zoom platform allowed us to reach our students remotely, the two of us knew we weren’t reaching them emotionally. And thus began an intergenerational transfer of knowledge and wisdom about online teaching, from Brian to Sean, Sean to Andrew, and now the three of us to our colleagues in this document.

None of us are experts in audio/visual technology. Like most academics, our focus is research and teaching, not building home studios and live streaming. However, we view our amateur status as a feature, not a bug. If we can do it, so can you.

Our goal is to write the tour guide that we wish we had when we started our journey into the World of Edcraft. Each of us has made a significant investment in online teaching technology, as well as a number of mistakes and miscues in applying that technology to our individual teaching contexts. We’d like to be able to share these experiences in the hope that it’ll save others some time and anguish, and improve online education for our students.

2. Teaching Philosophy

At the risk of being accused of academics, we begin with a brief and somewhat personal discussion about teaching philosophy. Not “Teaching Philosophy”—on which none of us are qualified to opine—but rather our own teaching philosophies, how we think about in-person versus online instruction and why we’ve each made the decision to invest in considerably more complex technology than any of us would have thought sensible or possible a few years ago.

2.1. Why In-Person Is Better Than Online

In most other modern pursuits, the ability of technology to improve our lives has become a cliché. Moore’s Law has transformed every industry, to the point where we now simply expect that each year will bring more powerful tools than the year before, whether it’s better smartphones, better cars, better medicines, or better videogames. But what about better teaching?
If technology has allowed us to exceed our expectations in virtually every other aspect of our daily existence—computing, entertainment, retail sales, telecommunications, transportation, finance and insurance, healthcare, and so on—so why hasn’t it had as much of an impact on education?

The answer lies in the evolutionary history of *Homo sapiens* and our cognitive faculties. It’s a well-established fact that humans, and most other mammals, are social creatures. This truism has an important implication for our cognitive functions—we become much more alert and attentive in the presence of other humans. This feature clearly confers survival benefits: physical distance is highly correlated with the potential harm others can inflict. As a result, we become much more focused and engaged as another human gets closer to us. Phrases like “you’re violating my personal space”, “you’re crowding me”, and “too close for comfort” underscore this basic principle of human biology.

This is why in-person meetings will always have an advantage over online interactions. Two-dimensional simulacra can only go so far in replicating a dynamic three-dimensional experience. And therein lies the challenge for online education.

The moment an instructor walks into a classroom, stands at the lectern in front of seated students, she commands some part of everyone’s attention. If we measured the physiological characteristics of each student in real time—heart rate, breathing rate, blood pressure, skin conductance, etc.—we would observe a noticeable difference in these metrics as the professor arrives, begins to speak, and paces across the classroom and up and down the aisles. As the instructor approaches one side of the room, these metrics rise for students on that side and fall for those farther away. A skilled educator instinctively knows this, and uses this to her advantage by approaching students to make a point, retreating back to the lectern to conclude that point and prepare for the next topic, and so on. Watching the pedagogical ballet of a talented teacher managing a lively class discussion is no less exciting than watching acrobats performing live on stage. OK, maybe it’s a bit less exciting, but you get the idea.

The point is that, if learning requires focus and attention, then in-person instruction will always dominate online instruction for purely biological reasons, other things equal. So the challenge of online instruction is making sure other things aren’t equal. To achieve comparable impact with online instruction, we need to use technology to alter the student’s reality, in much the same way that the Hollywood film industry, the videogame industry, the advertising industry, and the music industry alter our realities with their wares. A masterful exposition of the underlying scientific principles of how we learn is the recent book *Grasp* by our MIT colleague Professor Sanjay Sarma, a renowned mechanical engineering faculty member and successful entrepreneur who also happens to be MIT’s Head of Open Learning.
2.2. What Gamers Can Teach Teachers

This challenge isn’t new. In fact, the videogame industry has pretty well figured it out. As of November 2020, the global gaming industry’s revenue for that year was estimated to be $174.9 billion, which was $15 billion higher than the forecast six months earlier, thanks to the impact of the pandemic. In contrast, the global film industry generated revenues of $49 billion in 2019, which is expected to drop to $15.5 billion in 2020.

Apart from the obvious challenges of filmmaking in the midst of a pandemic, why are videogames so much more profitable than movies? Both involve dynamic two-dimensional displays of images with sound, and strong narratives that capture our hearts and minds. The key difference is engagement. While movies draw us in to the land of make believe, videogames allow us to interact with its denizens. In fact, gaming companies like Blizzard Entertainment, maker of the World of Warcraft, have created entire ecosystems in which humans can assume various personas and engage in real-life drama with other human players. The popularity of this game has reached such heights that concerns about physical addiction has been raised by many sources.

More recently, the rise of videogames as a spectator sport—now known as esports—highlights another key aspect of online interactions: humans watching humans is more captivating than humans watching animation, and humans watching humans live is more captivating than humans watching pre-recorded humans. Livestreaming is by no means new; TV shows like Saturday Night Live have, for decades, attracted viewers with their live broadcasts. But those of us who grew up watching SNL are probably still a bit puzzled by gamers watching other gamers play their games—when did that become a thing?

2.3. How Online Technology Can Facilitate Learning

It turns out that effective online teaching has a lot in common with effective gamer livestreaming, and it should come as no surprise that much of the home studio equipment we’ve adopted is the same used by gamers. In both cases, the goal is to keep the viewer engaged in as many ways and for as long as possible. And technology can help.

So how do gamers and videogame makers maximize viewer engagement? From our admittedly amateur perspective, these are the key elements:

1. Narrative
2. Continuous flow of action in sight and sound; never a dull moment, except for period breaks that provide punctuation for the action
3. Opportunities for two-way communication so viewers are also participants
4. High production quality

Narrative means a specific storyline or overarching theme to the livestream. Although gamers sometime host livestreams where their viewers are just “hanging out” with them, the more
popular streams involve specific activities, e.g., a competition, advice on how to defeat a specific boss, a tutorial on installing a piece of gaming equipment, etc.

To maintain engagement, it’s critical to keep viewers occupied with a constant stream of input that fills as many of the senses as possible. Of course, even gamers need short breaks every now and then, so it’s important to establish a certain rhythm of action, lull, action, lull, and so on.

But the best way to keep viewers hooked is, of course, to allow them to join in the action. While Hollywood may have figured out ways to transport us to other worlds, videogames allow us to live, breathe, fight, die, and regenerate in those worlds. In fact, watching a movie is no competition for being part of a movie and being able to influence its plot. This is what we need to do to teach online successfully.

In the remaining sections of this paper, we describe the hardware, software, and studio setups we use in our online teaching, and then provide three case studies for how each of us uses our own setup to suit our specific teaching styles and objectives. Now that you understand our goals—which are much the same as those of gamers—the motivation for the various components of our studios will become clear.

2.4. Tour Guide vs. User’s Guide

One last point of clarification is in order before we begin. In describing the various technologies we’ve adopted, we’ve decided not to write this document as a step-by-step user’s guide, but rather as a somewhat higher-level tour guide. The distinction may seem more a matter of semantics than substance but it’s worth pointing out upfront because readers may wonder why we don’t provide more direction for how to set up a Stream Deck or a GoXLR device. The answer is simple: there are already many excellent tutorials on YouTube and other online repositories that do this, so why re-invent the wheel?

But a more important reason is that these technologies change so quickly that no matter what we write or how we write it, by the time you read this, it will very likely be out of date. For example, when Sean and Andrew first began their process of setting up their online studios in March (Sean) and August (Andrew) 2020, the main piece of software they used for broadcasting their livestream was OBS Studio, version 25.0.1. However, a much-improved version, 26.1.1, was released on January 6, 2021 and several key features have changed. One of them is that the new release no longer requires an added plug-in to create a “virtual webcam” that provides the video feed for Zoom. Had we written down the step-by-step procedure for how to use OBS to livestream into Zoom in August 2020, those instructions would be completely irrelevant in January 2021.

The good news is that, given the size of the gaming community and how quickly they embrace new technologies, someone will have created a clear and often entertaining tutorial on how to
use this new technology as soon as it’s available. So rather than write a user’s guide that will become obsolete as soon as we post it, our intention is to write a tour guide that gives you the lay of the land in the World of Edcraft, so you can locate the general neighborhood you’re seeking even if a few streets get renamed. Each of us has also produced a series of videos about our studios as well as how we use them for online synchronous teaching, and we encourage readers who want to see, hear, and feel what it would be like to teach using our platforms to check them out.⁵

3. Our Home Studios and Online Teaching Formats

The basic approach that all three of us have taken in our online teaching efforts is to use software to create the particular format that suits our individual teaching styles—“weatherman” style for Andrew, “newscaster” style for Brian, and “talking head”/lightboard style for Sean—and then stream this format using Zoom, YouTube, or some other videoconferencing platform (Exhibit 1). By separating the streaming component from the online teaching format, we’re able to produce richer (and more computer-CPU-demanding) presentations that students find more engaging.

Exhibit 1. Basic input/output schematic of our online teaching platform. Various input devices such as audio, video, slides, writing tablet, document camera, and lightboard are incorporated into a software platform such as OBS Studio or Streamlabs, arranged in various “scenes”, and then streamed to students via Zoom, YouTube, or some other videoconference service.

The results of this approach are displayed in Exhibit 2, which contains screenshots of the different formats we use, and we provide brief summaries of each of our setups in this section. Andrew uses two primary scenes, one in which he stands in the middle of the frame when speaking

⁵ Andrew’s videos are here: https://youtu.be/jaFHhQktJiw (studio setup) and https://youtu.be/hmGV_c-krIU (teaching healthcare finance); Brian’s videos are here: https://www.youtube.com/watch?v=IrP-0bAMlZI&t=19s (studio setup) and https://www.youtube.com/watch?v=P5N9_hvc9AI (teaching statistics); and Sean’s six-video series about his studio and teaching experience is here: https://bit.ly/3uncIla.
without slides (Exhibit 2a), a second in which he stands to the right of a slide using a “weatherman” format (Exhibit 2b). Brian uses several scenes, but the common theme for most of them is a “newscaster” format in which he’s sitting at a desk and speaking into a broadcast microphone with either slides (Exhibit 2c) or a homework problem (Exhibit 2d) as the background. And Sean uses the widest variety of scenes: standing in front of the camera (Exhibit 2e), standing to the left of a slide (Exhibit 2f), a split-screen scene in which he takes up the left half and a document camera fills the right half (Exhibit 2g), and a lightboard scene in which he writes on a transparent surface filmed with a black background (Exhibit 2h).
3.1. Andrew Lo’s Home Studio

Because Andrew’s preferred online teaching format is the “weatherman” style in which he is standing in front of his slides and able to point to specific areas during his lectures, his setup consists of an adjustable-height desk behind which stands, facing his webcam, videoconferencing monitor, and studio lights (Exhibit 1, Exhibit 3a). Behind him is a green screen, and off to the side are two smaller computer monitors mounted to swing arms and his desktop computer (Exhibit 3b). Sitting on his desk are the computer keyboard and mouse, a Stream Deck (a programmable set of keys for automating many functions such as quickly switching scenes in OBS, launching or closing programs, playing music, etc.), the GoXLR (for managing audio inputs/outputs and sound creating audio special effects), the Atem Mini (for managing video inputs/outputs), and the computer speaker on/off/volume control, all within easy reach. On the floor underneath the desk is the footpedal control (for advancing/rewinding slides and other key presses foot). Appendix A3 includes a list of all the components along with a photograph in which each component is labeled with the corresponding number from the list.
3.2. Brian Steven’s Home Studio

Brian’s studio is a “newscaster” setup (Exhibit 3c) in which he’s mostly in a sitting position—except for occasional trips to the whiteboard—and speaking directly into a broadcaster’s
microphone, facing a tripod-mounted webcam and studio lights. On his desk are almost the same components as Andrew’s setup: keyboard and mouse, two computer monitors, Atem Mini, GoXLR, and two Stream Decks. His desktop computer is tucked underneath the desk. Appendix A4 includes a list of all of Brian’s components along with a photograph in which each component is labeled with the corresponding number from the list.

3.3. Sean Willems’ Home Studio

Sean’s studio (Exhibit 3d–f) is by far the most elaborate, consisting of a 420 square-foot room with two distinct camera locations from which he lectures: an adjustable-height desk similar to Andrew’s, and a separate area with a lightboard and its own webcam. At his desk area, he has a keyboard and mouse, computer monitor, a Stream Deck XL, and a document camera, and he faces a large videoconferencing monitor as well as a confidence monitor off to the side.

The lightboard station places the instructor behind a lightboard which is an illuminated glass board allowing students to see the instructor and the instructor’s writing at the same time. In contrast to the talking-head station, the instructor is always moving and visible at the lightboard station. There is a shock-and-awe aspect of the lightboard. It’s still novel enough that students have often not taken a class that uses the lightboard. Some subset of students is mystified by how the handwriting is not reversed. While one has to manage the space on the board properly, it is entirely possible to structure a board plan that is equivalent to the boards produced by a robust on-campus case discussion, as demonstrated in (Exhibit 3f).

The lightboard station requires the same input devices as the talking-head station. While the instructor will surely spend time writing on the lightboard and interacting with students, there is a keyboard and mouse to show computer content and a Stream Deck to automate the movement between modalities and camera stations.

Operating two stations at once does create some logistical challenges during class. There are four monitors in all: one confidence monitor for each camera station, one monitor for overlays at the lightboard station, and one computer monitor visible from both stations. There will surely be times the instructor will want to put the Zoom window on the active station’s confidence monitor. This can be automated through software but it still requires planning to move between stations. The computer and its monitor, pictured in (Exhibit 3e), are on a rolling stand so they can be moved between stations. The lightboard station also operates best in darkness (other than the lightboard’s presentation lights), so lighting has to be managed between station transitions. The bottom line is teaching from two stations significantly increases the coordination and planning required. The Stream Deck is instrumental in allowing the instructor to rapidly switch teaching modalities with the press of a single button.

Appendix A5 includes a list of all of Sean’s components along with a photograph in which each component is labeled with the corresponding number from the list.
3.4. The Trials and Tribulations of New Technology

What’s interesting about our home studios is there are a lot of moving parts, but none of them are particularly complicated. That is, they’re all off-the-shelf technology we interact with every day. The two challenges to overcome are integrating them into a residential space, and developing a teaching plan that best uses each component. Integrating them into the space is nontrivial because—assuming the instructor is not an audiovisual expert—small tweaks, like moving a camera five inches to the left, will affect desk placement, lighting position, sound levels, the place where the instructor should stand, and on and on. There are just so many knock-on effects from changing any one component that integrating the technology components is time consuming and tedious.

Even worse, many of these technologies don’t necessarily improve teaching quality; they only take the studio to the point where it’s just comparable to an on-campus classroom. The challenge of developing a teaching plan that best incorporates each modality of the studio is the more important challenge to overcome. It’s what the student experiences from the studio. The best way to employ this technology is a nontrivial task because it does not match how the instructor teaches on campus. It has all the requisite challenges of learning a new teaching format.

One common theme that all three of us learned in the course of our studio design and implementation is that, every so often, a technological glitch occurs that will take hours to sort out. And at the end of that process, we’re tired and emotionally spent, but triumphant in our newfound knowledge of how not to use the technology in ways it wasn’t designed to be used. If you enter this world of home studio development, be prepared to be frustrated beyond the breaking point from time to time. A certain Zen-like approach is probably necessary for preserving your long-run sanity. A more easily achievable solution is to develop a small network of like-minded colleagues—as the three of us have—with whom you can get and offer help and, more importantly, moral support.

4. 15.482 Healthcare Finance at MIT (Andrew Lo)

During the Fall 2020 semester, I taught a second-year MBA elective course called Healthcare Finance. This is a course I developed several years ago to focus on the role of finance in the healthcare industry, with particular emphasis on the application of novel financing methods to facilitate drug discovery, clinical development, and greater patient access to high-cost therapies. No prior knowledge of the healthcare industry or biomedical sciences is required or assumed, but this course is designed for students who wish to pursue careers in the healthcare and healthcare-investments industries, broadly defined.

The teaching slot assigned to me was Thursdays, 6:00pm to 9:00pm ET, which was not ideal, especially for an online-only format. However, it was a necessary consequence of the complex
scheduling challenges of Sloan’s combination of in-person, online-only, and hybrid courses, all delivered in a socially distanced manner to keep students, faculty, and staff as safe as possible.

This timeslot yielded 13 three-hour sessions, and the topics covered included: basic financial analysis for the life-sciences professional, the historical financial risks and returns of the biotech and pharmaceutical industries, the mechanics of biotech startup financing, capital budgeting for pharmaceutical companies, estimating probabilities of success for clinical trial outcomes using machine learning, and applications of financial engineering tools (e.g., portfolio theory, risk management, real options) and new business models (e.g., venture philanthropy, special purpose acquisition companies, etc.) to various biomedical challenges including cancer, Alzheimer’s, rare diseases, infectious diseases like COVID-19, and other illnesses.

4.1. The Challenge and Course Objectives

An online version of this course already existed prior to the pandemic. I taught this course for the first time in 2017, and all the lectures were videotaped and made into a massive online open course (MOOC) on the MITx/edX platform. Therefore, in principle, it would have been possible to have students enroll in this MOOC. However, given the overwhelmingly negative feedback we received from students during the second half of the Spring 2020 semester when all classes were switched to an online-only format, offering MOOCs for their Fall courses was simply not an option. The average tuition for a typical U.S.-based MBA program is approximately $75,000, and scholarships are exceedingly rare. Not only are these students paying full tuition with after-tax dollars, but most of them have given up well-paying jobs to enroll, hence the opportunity cost of their forgone salaries must be included in the cost of their education. Therefore, it is understandable that they have higher expectations for their curriculum. As one student put it: “I didn’t give up my consulting job and pay $75,000 in tuition for Khan Academy.”

But how can we meet their expectations with an online-only course, especially given the behavioral factors of live version remote interactions discussed in Section 2 (Teaching Philosophy)?

To solve this conundrum, I first asked what students find most valuable about business school besides academic subject matter, which they can access via Khan Academy and other online platforms. Why would they willingly give up their jobs and pay $75,000 to come to business school? The answer to this question laid the foundation for my online version of healthcare finance.

I concluded that business school students have at least five additional objectives beyond academic training: (1) networking opportunities with their classmates, faculty, and business

6 This course is now available on MIT’s Open Learning Library platform: https://openlearninglibrary.mit.edu/courses/course-v1:MITx+15.482x+1T2019/about

Electronic copy available at: https://ssrn.com/abstract=3793342
leaders; (2) exposure to the unique perspectives of faculty members and classmates through live interactions; (3) exposure to new industries and business leaders through action-learning opportunities; (4) assistance with career development; and (5) certification of a business degree. Given that the last two issues are not directly related to teaching, my focus turned to the first three objectives, but kept in mind the possibility of using the class to help develop new career opportunities for the students.

Would it be possible to meet, and perhaps even exceed, student expectations using the technology of online delivery platforms? In fact, I had a more ambitious goal: could we create an online-only course that was better than live, at least in these dimensions?

4.2. Course Design

I believe that the course design I finally settled on accomplished this goal. The four specific objectives were to exploit online technology to:

- Maximize networking opportunities for students with classmates, faculty and staff, and business leaders and mentors.
- Take advantage of the lower cost of participating in online classes to attract a larger group of outside speakers who otherwise would not have been able to participate in an in-person class.
- Provide students with unparalleled access to action-learning opportunities with mentors.
- Create new career opportunities for students interested in the healthcare industry.

To achieve these goals, the first challenge was to keep students engaged with the course despite the online-only format, so the first decision was to offer synchronous rather than pre-recorded lectures. Of course, all lectures were automatically recorded through Zoom (the platform chosen by MIT for delivering online-only classes), so if students missed a lecture, they had the option of viewing it afterwards, but the interactive nature of the class made it difficult to enroll in this class on a consistently asynchronous basis. Despite time zone challenges—including students in Asia and Europe—almost all of the 90 students taking the course for credit (and approximately 10 listeners) attended every lecture live.

Other methods for keeping students engaged were incorporated into various aspects of the course requirements:

1. Regular attendance and participation, in-class group exercises with assigned teams and peer evaluation after each class (20% of the total course grade)

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7 In the Spring 2020 semester, many of us were advised to prepare pre-recorded lectures so as to accommodate students in different time zones—this precipitated the “Khan Academy” critique mentioned above.
2. Weekly online pre-lecture questions, through the MITx platform (20% of the total course grade)
3. Six problem sets, also through MITx (60% of the total course grade, 10% for each problem set)
4. Volunteering to serving as moderator for a guest speaker (which allows the student to be excused from one problem among the first four)
5. An optional “practicum” which involves working in teams on projects proposed by practitioners who serve as mentors to the teams. If selected, this practicum excuses the student from problem sets 5 and 6, hence it comprised 20% of the total course grade for students choosing this option.

These requirements engaged students before class (through the reading assignments and the pre-lecture questions), during class (through the synchronous lectures), after class (through informal after-class discussions), and outside of class (through the problem sets, practicums, and informal meetings, office hours, and lunches). Let me describe each of these four components in more detail.

4.3. Before and During Class

Prior to each lecture, readings are assigned\(^8\) and students are asked to answer two to four pre-lecture questions on MITx before class. These questions are generally non-technical true/false or multiple-choice questions, and meant to familiarize students with the general theme of the upcoming lecture. They sometimes refer to the concepts covered in the reading materials so as to motivate students to prepare in advance for class, and are automatically graded by the MITx platform so students learn the correct answers (as well as their performance) immediately upon submitting their answers.

Each class began promptly at 6:05pm ET, and I typically started my preparations an hour beforehand by rebooting my workstation. I found this to be the most reliable way of avoiding OBS and Zoom crashes, and for ensuring that the other software components would run as expected. I then followed a checklist I developed for initializing my equipment that has become invaluable because of the sheer complexity of the set-up (Exhibit 4). One example of this complexity is that the order in which certain components are turned on actually matters—in my set-up, launching Zoom before OBS or switching on my webcam often causes Zoom to freeze and eventually crash.

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\(^8\) See the syllabus for 15.482 at the Google drive containing various documents cited in my online teaching videos: [https://bit.ly/3brm9C5](https://bit.ly/3brm9C5).

To build anticipation, I followed the typical gamer’s livestream approach of displaying a countdown timer on the course splash page about 30 minutes before class (see Exhibit 5). During this time, I would run through my slides one last time to check the animations and positioning of the text relative to my image, and then do a final check of the audio and video outputs. During this time, I would usually play music from my iTunes library for my own benefit, but students signing in early enjoyed this aspect of the class so it became a weekly tradition. I would choose a particularly upbeat piece of music during the final minutes before class to increase the energy level of the class, much the way performers use warm-up acts to prepare the audience. I have no idea whether this made a difference, but it did have a positive effect on my energy level so I can recommend it on that basis.
The three-hour class was divided into two parts—my lecture and then one or more outside speakers—separated by a 10-minute break. For classes with only one or two speakers, the lecture period ran from 6:05pm to 7:55pm, leaving approximately 50 minutes for the speakers. For classes with three or more speakers, the lecture period would typically conclude at 7:25pm, leaving a total of about 80 minutes to accommodate the additional speakers. However, this schedule varied from week to week because of scheduling issues with certain speakers (e.g., one speaker was based in Europe and requested an earlier speaking slot, so for that class, he and others spoke during the first half and I lectured during the second half). Because of these idiosyncrasies, it was critical to provide students with detailed schedules for each class in advance so they could plan accordingly—and to keep to that schedule as closely as possible—especially given the fact that a number of students were taking the class synchronously despite being based in Asia or Europe. An example of the posted schedules for classes 11–13 is given in Exhibit 6.
To keep students engaged throughout the lecture portion of class, I used three features of Zoom in addition to encouraging students to raise their blue hands for questions and comments: polls, breakout room exercises, and the chat window.

Poll questions ranged from students’ career goals (e.g., “I plan to work in healthcare after graduation: (a) yes; (b) no; (c) undecided”) to illustrative examples to highlight certain concepts (e.g., choosing among four investments with different risk/reward profiles). Each lecture contained at least one and as many as four polls, each lasting about 30 seconds, and although they were all constructed in advance, the TA entered each of them manually at the start of the Zoom session. This required further coordination between the TA and I prior to each class, which was part of the 30-minute preparation beforehand.

Breakout-room exercises typically involved applications of a concept just covered in lecture, e.g., how to compute the net present value of a drug candidate undergoing clinical trials, and took place in two parts. The first part involved sending students into pre-assigned breakout rooms of four to six students each for a 5-minute “icebreaker” session where they introduce themselves to each other. Then the students returned to class for additional lecture content, after which the breakout exercise is announced and then students are sent back into a 10-minute session with the same pre-assigned teammates to work on the problem. At the end of this session, students rejoin the main class and I ask for volunteers to present their team’s solution to the rest of the class. These two parts are clearly delineated in the lecture slide deck (Exhibit 7).

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9 Zoom does allow users to preload polls via .csv files and I have successfully used this feature before, but for some reason, we were unable to do so for this class hence the TA had to enter polls manually at the start of each Zoom session.
Exhibit 7. Breakout-room exercise slides for 15.482. Slide (a) announces the 5-minute ice-breaker session and slide (b) provides the exercise itself, on which teams of 4–6 students collaborated in 10-minute breakout-room session.

The purpose of separating the icebreaker from the exercise is to give students an opportunity to meet each other first and get introductions out of the way, so as to be able to devote full attention to the exercise during the second breakout-room session. The purpose for pre-assigning breakout room membership is to maximize the number of new contacts each student makes during the semester. Assignments are done via an integer-programming algorithm that “samples without replacement” (Xu, 2020) so each week’s breakout room assignment allows students to meet as many new classmates as possible (Exhibit 8).^{10}

^{10} A detailed description of the algorithm and corresponding Julia code generating assignments are both available at https://bit.ly/38vIRdb.
Exhibit 8. Optimization problem to generate breakout room assignments so as to maximize the number of networking opportunities among students during the semester. See Xu (2020) and corresponding Julia code for details, both of which are available at https://bit.ly/38vlRdb.

And the chat window is perhaps the most novel aspect of learning technology from the perspective of traditional in-person teaching. At first, I was taken aback by how much chatter was going on while I was speaking. But I quickly realized that, while some of the chats were social—which helps build camaraderie among the students, a particularly valuable thing for an online-only class—much of it was questions and answers between the students. Because of heterogeneity in the students’ educational and career backgrounds, some students had deep expertise in healthcare while others were totally inexperienced. The chat window allowed tremendous amounts of information to be communicated from one student to another and, in most cases, nearly instantaneously. In an example I provided in my video overview of this class, my use of the term “PBM” without first defining it prompted one student to ask his classmates...
via chat what this term meant, and he received four replies—each with different and useful aspects of the definition—within the span of 29 seconds.

Once I realized the power of the chat window in crowd-sourcing information that usually supplements my lecture, I encouraged students to make use of this important feature. Moreover, during presentations by outside speakers, I would make use of the chat window as well, pointing out connections between speakers’ comments and course content, or posting articles to support points made by speakers or students. To develop a sense for the value of these chats, I have included in Appendix A7 a portion of the chat transcript for one of my classes (de-identified to preserve my students’ privacy).

On occasion, discussions in the chat become so relevant to the topic I was lecturing on, or, in rare cases, so confused, that the TA—who was asked to monitor the chat window throughout the lecture—would interrupt me to bring the issue to my attention so that we could engage the entire class in its discussion. This is a critical role of the TA, and its importance to maintaining an active and productive class dynamic cannot be overemphasized.

The combination of blue hands, polls, breakout sessions, the chat window, and interactions with speakers implies that students are being engaged in some specific task requiring their active participation once every 15 minutes or so, which achieves the goal of maintaining their attention and interest level throughout the lecture portion of class. Exhibit 9 illustrates the duration between distinct activities in a typical class. In the context of an in-person lecture, these shifts in activities every 15 or 20 minutes would be considered by most teachers as highly disruptive to the flow of a standard lecture. This is due to the fact that the physical presence of a lecturer, and her ability to “read the class” and change the dynamics by stopping to take comments or cold-calling on students, allow her to engage students with very little effort. As discussed in Section 2, replicating that same level of engagement in an online class requires a great deal more effort, which includes periodic shifts in the activities of otherwise passive participants.
<table>
<thead>
<tr>
<th>Time</th>
<th>Delta (min)</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>6:05pm</td>
<td>—</td>
<td>Class begins</td>
</tr>
<tr>
<td>6:20pm</td>
<td>15</td>
<td>Poll #1</td>
</tr>
<tr>
<td>6:30pm</td>
<td>10</td>
<td>Breakout Session (icebreaker)</td>
</tr>
<tr>
<td>6:35pm</td>
<td>5</td>
<td>Class resumes</td>
</tr>
<tr>
<td>6:50pm</td>
<td>15</td>
<td>Poll #2</td>
</tr>
<tr>
<td>7:10pm</td>
<td>20</td>
<td>Breakout Session (exercise)</td>
</tr>
<tr>
<td>7:20pm</td>
<td>10</td>
<td>Teams report</td>
</tr>
<tr>
<td>7:30pm</td>
<td>10</td>
<td>Class resumes</td>
</tr>
<tr>
<td>7:55pm</td>
<td>25</td>
<td>10-minute break</td>
</tr>
<tr>
<td>8:05pm</td>
<td>10</td>
<td>Introduce student moderators</td>
</tr>
<tr>
<td>8:10pm</td>
<td>5</td>
<td>Students introduce speaker #1</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>8:55pm</td>
<td>—</td>
<td>Class ends</td>
</tr>
</tbody>
</table>

Exhibit 9. Schedule of activities of a typical 15.482 Fall 2020 class, with activities spaced as evenly as possible throughout the session to maintain student attention and engagement.

4.4. Guest Speakers

To increase student engagement during the speaker portion of the class, I chose a “fireside chat” format for all speakers rather than asking them to give prepared presentations. This had the dual purpose of minimizing the burden to speakers as well as maximizing the interactions between speakers and students, especially since I delegated the responsibility of introducing each speaker and moderating his/her fireside chat to student volunteers. For the first class, I took on the role of introducing the speaker and moderating his fireside chat, just to give students an example of what was expected, and then asked for volunteers for subsequent weeks.

The moderator role involved scheduling and preparing for a 30-minute prep call with the speaker the week before his/her visit to go over the topics to be covered, and to settle on the first two or three questions that the student moderator would ask the speaker before turning to the class for general Q&A. In addition to facilitating the fireside chat, these prep calls served another purpose: to give students opportunities to network with industry leaders, and to allow those leaders opportunities to mentor students. This second purpose was embraced not only by the student volunteers, but also by every single speaker.

Initially, I expected to assign one moderator per speaker, but due to popular demand, I assigned two to three moderators per speaker in most cases and this worked out very well. Without exception, all speakers said they thoroughly enjoyed interacting with their moderators during the prep calls, and the students were thrilled to have the opportunity to meet such extraordinarily accomplished individuals. Moreover, the class discussions generated by this format—and thanks in no small part to the coordination between speakers and moderators in advance—were lively,
uniquely informative, and truly inspiring. To acknowledge the time and effort involved in this role, moderators were excused from one out of the first four problem sets of their choosing.\textsuperscript{11}

4.5. After Class

To replicate the common practice of speaking with students informally after an in-person lecture, I offered to meet with students after each class in a separate Zoom session that was posted in the chat window by the TA at the end of class. I decided to hold my informal meeting in a separate Zoom session after a five-minute break for several reasons. The first was a desire to have a clear end to the formal class so students wouldn’t feel obligated to stay for the informal discussion (this was especially important given the late hour for students in the local time zone, not to mention those in Europe).

The second reason is that the class typically ended with guest speakers and I wanted to give students the opportunity to interact with them informally, without my presence, much like how an in-person class with guest speakers would conclude. My moving to a different Zoom session was less disruptive to these after-class interactions than asking our speakers and students to do so.

And third, moving to a different Zoom session after a short break gave students an opportunity to stretch their legs or get a drink, and gave me the opportunity to change the look and feel of the setting so that students would, in fact, feel less formal and more relaxed. Although this could have been accomplished at the touch of a button (thanks to the Stream Deck), having a separation in time and space between the formal setting of class versus the informal setting of my after-class discussion—complete with a slight wardrobe adjustment—served to underscore this shift (see Exhibit 10).

\textsuperscript{11} Problem set 6 was not included because it involved an innovative application of machine-learning to predicting clinical trial outcomes which, in my view, was higher priority due to its uniqueness and, consequently, its higher student-benefit-to-effort ratio. However, students choosing to do a practicum were excused from Problem Sets 5 and 6 both because of the practicum’s timing (see below), but also because the student-benefit-to-effort ratio was even higher for the practicum than these two problem sets.
Exhibit 10. Using different virtual backgrounds in distinct Zoom sessions to separate formal class time from informal after-class discussion in 15.482.

The last after-class task was to request that students fill out a survey form (provided in A8) consisting of an evaluation of the performance of: (1) their breakout-room teammates; (2) the instructor; (3) and each guest speaker. Students were also given an opportunity to provide comments and suggestions for improving the class (see Appendix A8, Question 4). Students were given 24 hours to complete the survey so as to collect feedback while the impressions from class were still fresh in their minds. Requesting feedback after each class may seem excessive, but it was particularly important given the experimental nature of this online class. And while immediate feedback can be somewhat tough on the instructor’s ego, it seems only fair, given that we instructors evaluate students on participation after each class. Moreover, some of the most effective components of the course were suggested by students through these surveys, e.g., having a separate “icebreaker” session prior to the breakout exercise, providing students with class schedules prior to each class, and allowing more than one student to serve as moderator for a given speaker.

All evaluations were scaled from 1 to 5, with the following definitions for each score: 1-ineffective; 2-somewhat ineffective; 3-neutral; 4-somewhat effective; and 5-effective. In evaluating their breakout-room teammates, we asked students to also include their own name in the list so as to preserve their anonymity. These breakout-room performance evaluations were averaged across all classes and incorporated into the students’ class participation grade, hence the students took these collaborative exercises—and the evaluations—seriously.

4.6. Outside of Class

I used several means to maintain student engagement outside of class. The first involved 15-minute informal meetings with groups of three to five students during the first two weeks of class. These meetings were extremely helpful in putting names to faces, learning more about the students’ backgrounds and career objectives, and getting students to meet each other. What I learned about the students through these meetings also allowed me to draw upon the rich pool of their experiences during class discussions. For example, in reviewing a specific pharmaceutical company’s clinical trial outcome, I was able to ask one of the students—who, I learned, worked

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12 The Qualtrics platform does not record identities of participants but if they fail to omit their own name from the evaluations of breakout-room participants, we can infer their identities because we know the breakout-room assignments.
there as a summer intern—to describe the mood at the company during the period leading up to the trial outcome.

These informal meetings did require a significant investment of time at the start of the semester, and was logistically challenging to schedule (reserving a block of hours and posting sign-up sheets helps), but it was well worth the investment and paid many dividends during the rest of the semester.

The second means for maintaining student engagement is holding informal virtual drop-in lunch hours with my TAs each week. Students were asked to sign up for a 15-minute slot in advance if they wanted to discuss a specific issue, but were also invited to drop in for informal discussion if they wished. During periods when no students showed up, I would use the time to discuss various aspects of the class with my TAs. These informal gatherings were similar to the meetings during the first two weeks, but as the semester wore on and I got to know the students better, these informal lunch meetings became more engaging and lively.

4.7. Practicum

The third, and most important, component for maintaining student engagement outside of classes was the optional “practicum.” This was a project-based exercise that took place over a particular three-week period in November 2020 in which teams of three to seven students worked on live problems posed by healthcare practitioners and researchers. Projects ranged from developing a proposal to commercialize therapeutics for ultra-rare diseases to determining the cost of capital for a gene-therapy reinsurance company. Students were given a list of these projects—each described in a one-page summary by the mentor associated with it (a sample one-pager is given in the course syllabus), and then allowed to sign up for their top choice. Teams were formed on the basis of these sign-ups.

Each team hosted one 45-minute Zoom meeting with the mentor at the start of the three-week period, during which the mentor would provide more background for the project and offer some guidance as to possible directions to explore. However, it was up to the team to decide how best to address the challenge. Mentors were not expected to have further contact with the team until the end of the three-week period (although almost all of them did have additional contact, voluntarily and enthusiastically), at which point each team was to present their findings to their mentors in a 1,500-word memorandum and a 30-minute Zoom presentation. These final presentations were recorded, made available to the rest of the class, and the practicum was graded on the quality of both the memorandum and the presentation.

Given the workload involved in this project, students opting to participate in a practicum would be excused from Problem Sets 5 and 6, which were assigned and due during this same three-week period in November 2020. Of the 90 students enrolled in the course, 50 participated in 10 different practicums, and the outcomes were nothing short of phenomenal. All the mentors
commented on how impressed they were with the memoranda and presentations, and the fact that they planned to make use of some of the students’ recommendations. They also enjoyed their interactions with the teams, and several have followed up with students in various ways, including continued collaboration on their projects, exposure to current industry practices and issues, and, in several cases, job interviews.

4.8. Did It Work?

Recall that the four objectives for the online edition of 15.482 were:

- Maximize networking opportunities for students with classmates, faculty and staff, and business leaders and mentors.
- Take advantage of the lower cost of participating in online classes to attract a larger group of outside speakers.
- Provide students with unparalleled access to action-learning opportunities with mentors.
- Create new career opportunities for students interested in the healthcare industry.

Based on the final course evaluation for 15.482 administered by MIT (not the weekly evaluations administered by me), and qualitative feedback from speakers, mentors, and teaching staff, the format and structure of the online version coupled with the delivery technology was a success from the perspective of students, faculty, staff, and speakers and mentors.

Although students acknowledged that online interactions were inferior to in-person meetings, the lower cost of conducting meetings online provided much greater opportunities for networking, mentorship, experiential learning, and career development, especially with the extraordinary group of business leaders and academic researchers who participated in the class. The practicum was perhaps the most powerful illustration of the potential benefits that an online

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\[13\] MIT’s subject evaluation process for Fall 2020 allowed instructors to include two questions customized to their specific courses. In response to the question “How valuable was the incorporation of guest panelists and student moderators into the curriculum?”, the mean response was 4.8/5.0 and the median response was 5.0/5.0 (with the rating Scale: 1=Not at all, 2=Only slightly, 3=Somewhat, 4=To a great extent, 5=To very great extent). In response to the question “How successful was this online-only course in achieving its goal of surpassing an in-person version in some aspects?”, the mean response was 4.7/5.0 and the median response was 5.0/5.0 (with the rating scale: 1=Strongly Disagree, 2=Disagree, 3=Mixed, 4=Agree, 5=Strongly Agree). In response to the primary course evaluation question “Recommend Subject,” the mean and median response was 5.0/5.0 (with the rating scale: 1=Strongly Disagree, 2=Disagree, 3=Mixed, 4=Agree, 5=Strongly Agree).

\[14\] For example, among the 12 mentors there was uniformly positive feedback, and this was a typical response: “Thank you so much for the opportunity to do this. I so enjoyed meeting and learning from your students! I thought they did a wonderful job and was particularly excited about their insights into connecting with families in China and of course connecting with venture philanthropists. I would have not know how to do either of those things without them! I thought their work was thorough, well organized, and well presented and filled with good, practical ideas we can implement! I am so grateful to them.”
platform can provide, but even the informal lunches showed how technology can give both students and faculty new ways of building community in the absence of in-person meetings.

To quantify the degree of networking facilitated by class interactions, we tracked all class-facilitated first-time meetings throughout the semester between every pair of students. These first-time meetings are displayed in Exhibit 11, which is a $90 \times 90$ matrix where the $(i,j)$-th element is colored green if students $i$ and $j$ have met during a breakout room, practicum, moderator meeting, or informal meetings and office hours with me. Based on this data, the average number of new contacts made by students in the class was 43, the minimum was 35 and the maximum was 51.

Of course, first-time meetings do not necessarily translate into meaningful connections between peers, but it does quantify the degree to which the online platform and our class activities can boost networking objectives. It would be useful to conduct surveys of in-person classes to assess the number of first-time meetings in traditional classroom settings to see whether the online platform truly dominates. If we had included first-time meetings with speakers and mentors as part of our metric, there is no doubt that the online platform yields an absolute advantage over in-person classes. These observations lead to the natural hypothesis that a hybrid course—one with in-person lectures as well as some online components—could be superior to both alternatives.

Exhibit 11. First contact matrix for 15.482 Fall 2020 students. Cells $(i,j)$ highlighted in green represent class-facilitated contact between students $i$ and $j$ at some point during the semester.

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15 When multiple students meet with me at the same time during office hours, I make it a point to introduce the students to each other at the outset if they haven’t already met.
4.9. Lessons Learned

There are two main issues with the online edition of 15.482 that instructors should be aware of when thinking about using this format. The first issue is that the use of so many outside speakers—we hosted 32 over the course of 13 required classes and one optional class—necessarily required reducing the amount of lecture material I would have normally covered in this course. The content I chose to omit in favor of speakers were of two types: (1) additional illustrative examples, including extended case studies, that show how to apply concepts such as net present value calculations, cost of capital estimation, and capital budgeting decisions using real options, decision trees, and Monte Carlo simulation; and (2) more technical content such as portfolio optimization for biomedical assets, estimation of probabilities of success for clinical trials, and applications of machine learning to forecasting clinical trial outcomes.

This decision was motivated by the four objectives described above, especially the desire to give students unique access to extraordinarily accomplished business leaders and academic researchers who would ordinarily not be available to us in an in-person setting during normal times. Moreover, if the primary purpose of the omitted content was to provide students with business context and exposure to best practices, that was achieved much more effectively by our speakers, many of whom pioneered the very business models I would have lectured about. Finally, the omitted material was, in fact, available online through the 15.482x MOOC that I developed a few years ago. Links to that material were posted on the course website.

The second and more important issue with the online version of 15.482 is the heavy workload for students, faculty, and staff. The increased workload for students came primarily from the practicum, which ended up involving far more time and effort than two problem sets’ worth. However, there is no easy solution to this problem because allowing students to substitute three or four problem sets for the practicum—which may be a more equitable trade-off in workload—implies that those students will miss out on important training covered by those problem sets. Also, my sense from working with the practicum teams and their mentors is that the extra effort students expended in the practicums was largely the result of their passion for their chosen problems (which is one important reason to allow them to choose projects rather than to assign them), and their own commitment to the highest standards of excellence. Perhaps the most balanced solution for future renditions of the practicum is to inform students in advance that the workload will be greater than that of two problem sets, but what they receive in return is practical experience that they can’t get any other way.

The workload for the teaching staff was also greater. The role of the TA during class was critical, as discussed above, but other important responsibilities of TA included offering recitations, office hours, updating problem sets and providing answer keys, and supporting practicum teams. I was fortunate to have recruited one of my top Ph.D. students, Qingyang Xu, to TA the course, and he was exceptionally committed to this position, as well as my unique goals for the course. For
example, he almost always responded to student emails within 30 minutes so students seeking help would not be kept waiting and lose engagement. He set up dozens of individual Zoom meetings—some taking an hour or longer—outside of his regular office hours and weekly recitations to help students with problem sets and practicum problems, and quickly became an integral part of the students’ learning experience. Such responsiveness is, of course, highly dependent on the particular personality of the TA, but it would have been impossible without the online technology. Given this workload, one TA was insufficient for 90 students, so I asked a former TA for the in-person version of 15.482, Zied Ben Chaouch, for help and he graciously agreed to volunteer in a supporting role.

The role of the course assistant was also critical, especially for managing the logistics of meetings and communications with all the speakers, mentors, and students. While many of these meetings were scheduled by the students themselves, initial contact with speakers and mentors was my responsibility. Subsequent contact to provide Zoom links and other logistical information was the responsibility of the course assistant, Lena Ngor, who did an excellent job managing the logistics of the entire class.

Finally, my own workload was considerably higher than any in-person course I have ever taught. Part of this increased workload was due to my own lack of experience with online technology, and the lack of institutionalized support for the type of lecture style and classroom experience that I wanted to achieve. That may change over time as MIT invests more resources into supporting online teaching, and as I develop more experience with this platform. But another part of the increased effort is to be expected for any form of online teaching. As discussed in Section 2, substituting in-person interactions with online technology is extremely difficult and requires many more person-hours to achieve anything close to comparable impact.

To differentiate between these two types of increases in workload, I have separated the sources of incremental effort required for the online version of 15.482 into two categories in the following lists:16

One-Time Incremental Start-Up Effort:

- Build home studio (one week, given the resources provided in this paper and the corresponding videos, and once all the parts have arrived)
- Learn how to use and maintain each component (three weeks, once the studio is fully operational)

16 By “incremental effort,” I mean the effort that is unique to an online-only offering. Therefore, I haven’t included things like updating lecture contents because that needs to be done irrespective of the delivery platform.
- Convert pre-existing conventional powerpoint slide decks to an online format (5 to 10 hours per 90-minute lecture, depending on the degree of animation, sound effects, polls, and breakout exercises)

Recurring Incremental Effort:

- Maintain studio, e.g., update software, replace failed components, etc. (1-5 hours per week)
- Invite speakers, explain fireside-chat format of the class (15-30 minutes per speaker)
- Invite practicum mentors, discuss possible projects with each mentor, edit one-page descriptions provided by mentors, view and grade final presentation of each team, follow-up with mentors after the final presentation (3-5 hours per project)
- Rehearsals alone and with TA(s) to ensure that the powerpoint presentations work as expected on OBS/Zoom, and to practice the timing of the animations, sound effects, polls, and breakout sessions (1 to 2 hours per 90-minute lecture, not including time spent updating lecture contents)
- Initial informal 15-minute meetings with students in groups of 3-5 students during the first two weeks (3 blocks of 2-hour meetings for 90 students)
- Informal lunches/office hours (1-2 hours per week for a class of 90 students)

Such incremental effort is currently not typical among faculty at universities where hiring and promotion decisions are based largely on research impact and productivity rather than teaching. But even at research-oriented institutions, faculty may still be drawn to invest in their teaching under certain conditions. The desire to have impact on the next generation of business leaders is compelling motivation for many faculty. The need to “step it up” for our students in the midst of a pandemic-induced lockdown is another source of motivation for my colleagues and me. Also, if it’s possible to design a course that aligns with a faculty member’s research agenda—as was the case for me with 15.482—then faculty can and will devote significantly more time and effort to course development and teaching without hesitation or regret.

In my case, the opportunity to interact with and learn from highly motivated and engaged students, guest speakers, and mentors has contributed significantly to my own research, and by bringing some of that research into the classroom, I believe that students will be better prepared for careers in the healthcare industry. To the extent that universities can craft course offerings to match more closely the research interests of their faculty, there’s no limit to the innovations that faculty will bring to their classrooms.

5. Statistics 201 at the University of Tennessee (Brian Stevens)

Statistics 201 is the introductory statistics class at the University of Tennessee, Knoxville, taught through the Haslam College of Business, that services students from all across the university. Over 1,200 students take it per semester, with backgrounds ranging from nursing to the sciences,
as well as business majors. About 70% of the class are sophomores, and we require only calculus as a prerequisite; no statistics background is assumed.

Before the pandemic, the course consisted of about 115 students per section. It currently has 345 students in the online-only section, roughly equivalent to triple enrollment. Four faculty members currently teach the course including me; I have three sections, and teach over 700 students.

The online-only class meets in live or synchronous sessions on YouTube—not Zoom—twice a week (Mondays and Wednesdays or Tuesdays and Thursdays) in the early afternoon local time for 75 minutes each, for fifteen weeks. This works out to be about 28 or 29 sessions per semester, depending on which days the section meets. Each class has its own unlisted playlist on YouTube (Exhibit 12).

Exhibit 12. Youtube playlist for Stats 201 class.

5.1. The Challenge and Course Objectives

My entry into the world of online teaching was really a stroke of good luck. I started my teaching career as a graduate student in 2011. The department head at that time, Dr. Ken Gilbert, recommended that I be appointed a senior lecturer. Following the retirement of Dr. Ramon Leon, the department gave me a chance to continue and expand its online program.

When I first started teaching online at Haslam, I did it from a mostly-empty classroom using Zoom. I brought my computer to the podium facing me while I faced the webcam which was placed in the midst of a few students who attended in person. I focused on student interactions by looking directly into the camera as much as possible. It helped that I positioned my laptop so it was on the podium just below the camera’s line of sight, hence my looking at the podium computer would be seen by the class as looking at them (Exhibit 13). This allowed me to shift
back and forth between using my computer (I used Excel, Stata, and other statistical software packages), which was screenshared with the students, and lecturing. From these pretty humble beginnings, little by little, I added further refinements to this platform and received very positive feedback for my setup and quirky style (you have to watch one of my lectures to understand what I mean by that).

Exhibit 13. Original Zoom format of online version of Stats 201.

In 2013, I was asked to design an asynchronous class for Statistics 201 for the Business Online Summer Session program. For that class, I was filmed at a higher level of production quality than the YouTube videos I had previously made at home. This is probably where I caught the video bug. After Haslam built a dedicated studio for online teaching in 2019, it occurred to me that we could use it to make online teaching a much bigger thing. Why not just do all of it live? After all, this is what streamers do all the time on YouTube gaming or Twitch, and include a number of Hollywood-style elements like intros, outros, music, sound effects, and other captivating features (Exhibit 14). So why couldn’t we bring it into the classroom?
With the assistance of my colleagues Mark Collins, a strong proponent of technology-enhanced education at the university, and Jason Greenway (wielding the pink lightsaber in Exhibit 14), who assisted with the graphics—and inspired my use of Adobe After Effects for my online classes—I built my home studio. The only additional piece of equipment I needed was a better microphone, which I received as a Christmas gift.

5.2. Course Design

My goal behind the online version of Stats 201 was to do things you could never do in person, and make the class more fun than you could ever be in person. This obviously keeps student engagement high. A digital native myself—I have fond memories of my family's Texas Instruments computer from 1986, when I was four years old—I was inspired by well-produced shows performed live on popular streaming sites, especially gaming livestreams. I wanted to incorporate the same sort of interaction with the performers, and the chats between different viewers, as key design elements in my online class.

The class requirements include:

- 10 visualization assignments
- 3 tests
- 2 projects
- 30 quizzes
- 20 homework assignments

Class requirements include 10 visualization assignments using the JMP software package, which are graded on clarity and facility in presentation. They cover basic statistical concepts, e.g., performing a t-test. There are also two projects later in the semester that are more difficult. The first is writing a technical report with a clear executive summary that includes its key findings,
using a prewritten report as the starting point. This is basically a "gimme" for the students, mainly to help build confidence at the outset and to get them to think visually. The second project, however, combines the conceptual knowledge gained from the visualization assignments and the executive summary of the first project into writing a full paper.

The class also includes quizzes conducted through myPearson (the text used is also from Pearson), and three tests conducted through RespondUs Lockdown Browser. These tests are ninety minutes in length, about 60 questions each, with an average score in the mid-70s. There are 10 regular "Canvas content" quizzes, which incorporate questions that are in the question bank for the tests. I also use the Kahoot! game-based platform for review sessions, which incorporate these questions. There are also homework assignments through myPearson, which account for 5% of the grade, which I’ll say more about below.

5.3. Before and During Class

Before each class, I want students to look at the homework on myPearson. They are allowed an infinite number of attempts on it, so there’s no downside. If a student doesn’t work on it, I’ll send an email to encourage them.

The class uses the online YouTube chat extensively, using its tagging functions to contact specific people, including questions for me. This can occur before the class formally starts. I will usually put on a one-minute countdown timer immediately before class, and a series of timers guide my actions throughout. I have a saying that students know well and have come to appreciate: "We start on time. We end on time."

The class begins with a short opening video segment on the YouTube live stream, lasting 10 to 15 seconds. I begin immediately afterwards, starting with a five-minute recap to get the students' mindset realigned with the class, and the upcoming test and assignment schedule.

I use preset video segments and prewritten whiteboards for my lectures, and I monitor the chat for questions. Throughout the class, students are either chatting with me or with each other. What makes Stats 201 really innovative, however, is that during the lecture material, I’ll loosen up the class with techniques taken from gaming—maybe introducing a “Boss Battle” (Exhibit 15) or a "Speed Run"—to keep the lecture from being too static.
A Boss Battle is a segment designed to prevent the flow of a lecture from becoming tedious. I use it when a test or project is coming up and I tell the students that it’s like the “Boss” in a videogame and it taunts you, so I’ll use an evil “voice of God” special effect via the GoXLR and tell the students “the test is coming, and if you don’t prepare, you’re NOT gonna like your grade, ha ha ha!” I also use the Boss Battle metaphor when I’m about to cover a difficult topic like Type I versus Type II errors, to get the students prepared: "This is going to be tough, but don't get discouraged—you’re going to beat this boss."

A Speed Run (Exhibit 16) serves a different purpose. This is a timed exercise in which I try to explain a concept as quickly as possible on a clean slate (usually a blank Word document that I bring up next to me), somewhat similar to a game of Pictionary, to energize students about that concept.
Another graphic innovation is “Tiny Brian,” (Exhibit 17) a smaller video image of me that students find endearing, and will message “Protect tiny Brian” in the chat and ask, “Can tiny Brian explain this to us?” I try to monitor the emotional reactions of the class to each of these innovations, sometimes relying on skills I developed as a semi-serious online poker player (back in my “bad ole days”). Other characters include a giant backwards image of me nicknamed “Brawl,” (an inside joke stemming from a student’s misspelling of my name in the chat). To mix up the format even more, I often include “Wacky Daily Events” interludes to add further stimulation. My fiancée, Chelsea, assists in the development of these innovations and their associated audio components, such as voiceover work.

I’m also a big user of the program Mu Bot to carry out other functions within the YouTube chat. This software—using the Streamlabs Chatbot—tracks how much people are interacting in the chat, and assigns them points according to their activity. These programs came out of the gaming community, where they’re used to reward greater participation. Students feel a sense of accomplishment when they rise up the ranks of participation. This measure of participation is also used in the final grade instead of the more common practice of rounding up a student’s grade at the end of the semester if they happened to be an active participant.

Students can ask questions on chat at any time. I wait until I finish discussing a particular point and then turn to their question. This does take some practice and awareness. In one form or another, I’ve been teaching this class online for nearly a decade, so I’ve developed a certain intuition for what students find difficult and easy. If I sense growing frustration with a particular concept, I’ll take a break and switch the format to a brief “Talk With Brian” session where I’ll turn
to some non-class topic (e.g., a new videogame system, or the Vols game last weekend), and if things go too far afield, I may switch to a speed run. It’s really like playing an instrument during a concert—you have to watch the crowd.

5.4. After and Outside of Class

After the class ends, I change the visual environment once again, announcing that the class is over with a big sign to give students the cue that there is no more formal instruction. However, I always stay online to answer questions in the chat.

During pre-pandemic days, after the first day of class I would organize field trips to my office for the online students to grab some candy, to create a greater sense of interaction with students. Today, I organize surprise streaming sessions and use email to maintain personal connections. I also monitor a Discord channel for my students (another gift from the gaming industry), which is available for them to use at any time and includes video and voice chat. Exhibit 18 contains a screenshot of the site where students can request a role on the server associated with their assigned section. This limits what they can access on the server to their section only.

Exhibit 18. Screenshot of the Discord channel where students can request a role on the server associated with their assigned section. Note that 291 of the 345 enrolled students participate on this platform, underscoring its popularity.

Similarly, I used to have regular office hours where between 10 to 40 students would typically show up (eight students in my office at any given time, and overflow in outside cubicles). Discord and YouTube sessions are a partial substitute for this personal interaction. The Youtube office hours sessions are recorded and annotated (which is a big time commitment), and the corresponding chat is also recorded.
I’m also a big fan of Kahoot!, an online interactive quiz game show (available at Kahoot.it) in review sessions, typically on Sunday nights. These quizzes are conducted rather like a tournament, and include questions about major topics covered in each chapter. They include a leaderboard, and the top-ranked students receive prizes with real value in the form of Amazon gift cards. Up to 200 students have been known to participate, but on a typical night, the number is closer to 100 to 150.

![Kahoot! screenshot](image)

Exhibit 19. First Kahoot! of the semester for Stats 201 introducing students to this platform.

5.5. Lessons Learned

Two of my initial concerns about teaching online were that students would have a harder time absorbing the material, and that I wouldn’t be able to cover as much material. I have to say that I’m proud that neither of these worries have come to pass based on my course evaluations (Exhibit 20). My teaching ratings have actually increased slightly with the online-only sections (Exhibit 20b), and the students have done as well if not better on the same exams we use for in-person sections. To my great relief and delight, students really like the online format.
One potential issue with the online format at is the potential misuse of the chat function during class, causing disruption and ill will among its participants. I haven’t had more than one or two issues in all my years of online teaching, but when it does happen, it’s important to put a stop to it quickly and decisively. Establishing the right culture in the chat is critical, not only for avoiding these kinds of issues, but also for creating norms that will facilitate more active and supportive interactions.

One way to achieve this elusive goal is to give all students “channel moderator” status. This means that each student has the administrative rights to block another student from the chat, in much the same way that a systems administrator can lock a user’s account. Giving every student such authority may seem like a crazy idea, but being endowed with this elevated status seems to empower students to take greater responsibility for the quality of the chat, and the results speak
for themselves in terms of how well the chat window has functioned throughout my years of online teaching.

Another method I’ve come up with for maintaining a positive vibe and a sense of fun is to inspire a group identity. For example, during one semester, the students spontaneously came up with the “Stats Nation” meme, and it stuck. Another semester, the students coined the memorable quote “Vols help Vols” (the students at the University of Tennessee are known as the Volunteers or Vols). I maintain a list of quotable quotes and in-jokes from the chat—in the format of a “leaderboard”—that students can access throughout the semester, and it’s surprising how much camaraderie this generates. It will often “make [a student’s] day” to see their quote appear on the leaderboard.

Maintaining the right level of connection with students is key to this process. I’ve noticed that some students assume an inappropriately informal attitude in the online student-teacher relationship at the beginning of the course, so I gently correct them. But on the other hand, I also enjoy making a personal connection with my students and try to encourage this. For example, one of my students discovered during office hours that he and I shared an interest in Korean popular music or K-Pop, so he sent me a recent favorite of his and we chatted about this after class. By engaging with students both in and outside of class, we’re able to develop an online rapport that I’m not sure many faculty are able to achieve with their in-class students.

6. 15.761 Introduction to Operations Management at MIT (Sean Willems)

On April 22, 2020, I learned I needed to deliver my summer operations management course, 15.761, fully online. I spent 14 days trying to find studio space, before my family graciously volunteered to give up space in our house. The studio shown in Exhibit 3d–f was designed and built in 30 days. Five experiences most influenced my course design:

1. In collaboration with Stephen C. Graves, creating two MITx courses: 15.762x Supply Chains for Manufacturing: Inventory Analytics and 15.763x Supply Chains for Manufacturing: Capacity Analytics. These eight-week courses have each run multiple times with thousands of participants and hundreds of verified learners;
2. In the fall of 2019, developing supplemental online content for my on-campus graduate elective BZAN 555 using the Haslam College of Business’ lightboard studio;
3. Teaching online class sessions in the spring of 2020. I was not the instructor of record for any class but I did lead class sessions for cases I had written;
4. Watching my college-aged children shift abruptly to online distance learning in the spring of 2020; and
5. Reading the student feedback UT and MIT provided faculty regarding the student experience with online learning in the spring of 2020.
These experiences gave me the opportunity to reflect on the profound differences between asynchronous online courses (i.e., MITx) and synchronous on-campus courses (i.e., MIT and UT). As an operations person, I immediately mapped this to the educational equivalent of the product-process matrix, as shown in Exhibit 21.

<table>
<thead>
<tr>
<th>Student Location</th>
<th>Online</th>
<th>In-Person</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spring, Summer 2020</td>
<td>Traditional edX/MITx</td>
</tr>
<tr>
<td></td>
<td>Traditional On-Campus</td>
<td></td>
</tr>
</tbody>
</table>

Exhibit 21. Course delivery can be mapped to the dimensions of student location and delivery method.

For those unfamiliar with the product-process matrix, the core insight is that the main diagonal is an efficient use of resources, and the off diagonal is inefficient. From Exhibit 21, this insight implies that online-synchronous courses are potentially suboptimal in terms of faculty effort and the student experience. Furthermore, my MITx experience convinced me I could not easily transfer my on-campus course to a synchronous online format.

I have heard my colleagues say our competition is Netflix, TikTok, YouTube, and similar platforms. I disagree. Our competition is our own teaching, reimagined in a world of TED Talks and high-quality talking head productions (e.g., Frontline, 60 Minutes, etc.). For summer 2020, I had the added challenge, relative to the spring semester, that the students had never seen a high-quality, on-campus business school product. Students that have seen us in the classroom understand the mapping from on-campus to online. If they have never seen the on-campus product, they don’t know what they don’t know. For these new students, the production quality really does matter.

In 2018, I was teaching the on-campus equivalents of the MITx courses when I agreed to participate in 15.762x and 15.763x. I remember thinking how great the timing was, because we could videotape the on-campus courses and integrate them into the asynchronous format of MITx. After taping four on-campus classes, I had a discussion with John Liu, now MITx Digital Learning Fellow. After reviewing the videos, John said:

These videos are great but we can’t use them. They perfectly capture the on-campus experience. Online learners watching these videos would come away wanting to be on campus at MIT, and they are not on campus at MIT. Learners don’t want to know how great MIT on-campus courses are. They want the content from MIT courses presented in a way that matches how they learn online.

John’s comment had a huge impact on my thinking, because it was so true to my experience. When we design online asynchronous courses for MITx, our major goals are scalability and clarity.
We’re trying to remove unnecessary ambiguity that, to a certain extent, we often keep in our on-campus courses because it promotes critical thinking and shared learning. I believe online asynchronous classes strive to achieve minimal sufficiency where the minimally sufficient bar is quite high, while on-campus synchronous courses promote profound comprehension.

COVID-19 has forced a learning model on us that is neither on-campus and synchronous nor online and asynchronous. Instead, it’s an online synchronous class that attempts to replicate the on-campus synchronous experience. My MITx experience was invaluable in helping me realize how hard this transition would be.

6.1. Studio Design Criteria

The on-campus teaching process cycles between teaching modalities. The instructor walks around the room, facilitates class discussion, writes on the board, and projects applications onto a display. To more closely replicate the on-campus experience using Zoom, I needed to make two changes. First, I used Open Broadcaster Software (OBS) as the command center for the studio, letting it serve as the virtual camera Zoom uses to broadcast content from the studio cameras, the document camera, and any application on the computer. Instead of Zoom using a camera for the video feed, Zoom uses OBS as the video feed, and the instructor’s choices on OBS dictate what is broadcast through Zoom to the audience. Second, I created two camera stations that I moved between, depending on the on-campus teaching modality I was trying to replicate: the talking-head station (Exhibit 2f), which places the instructor behind a standing desk equipped with a document camera and a personal computer, and the lightboard station (Exhibit 2h), which places the instructor behind the lightboard.

The stations engage students differently. The talking-head station is general purpose while the lightboard station is immersive. The talking-head station allows the instructor to easily converse with students, facilitate class discussion, write with the document camera, and present material from a computer. The station mimics the on-campus student experience by presenting a common image of the instructor across modalities, albeit cropped and sized depending on the modality. A powerful benefit of the talking-head station is the single-camera view of the instructor does not change across teaching modalities. The camera image gets cropped, sized and repositioned but the perspective remains constant. This exactly mimics the on-campus experience, particularly because all of the camera views keep the instructor large enough for the student to notice the instructor’s mannerisms and movements that are part of any normal classroom session.

6.2. Course Structure

The introduction to operations management course, 15.761, is graduate-level course offered as part of the MBA core curriculum at most top-tier MBA program. There are 24 class sessions, with each major course themes: process analysis, quality, and supply chain management. Each theme
introduces a base mathematical model that is extended in subsequent class sessions. The course has a practical focus, with the intent to demonstrate how these models can be solved, and implemented, in the real world. The core teaching challenge is to properly foster, and then resolve, ambiguity. The students begin the course thinking “the math” underlying the model is the hard part of what they have to learn. They come to realize the model, and its underlying mathematics, is the easy part. The hard part is understanding how to put the model in context, and implement it in reality.

15.761 is a case-based course. A case is 10 to 20 pages that describe facets of a business problem with sufficient detail allowing the students to apply, and exercise, the model. Successful case teaching requires students to be “immersed in the moment.” That is, they have to take ownership of the case’s problem, and its solution. They have to be committed not only to their own solution, but to each other’s solutions. In this way, the case reflects the real world where one has to get their colleagues on board with their preferred solution. Furthermore, there has to be a receptivity and willingness to bog down in the details of the case. It is these details that are critical to understanding the specific model that will be constructed, and the implementation plan that can be successful in practice.

Teaching 15.761 online required three significant changes to the structure of course, relative to the way I teach the course on campus. In particular, I had to reallocate class time, lead with model discussion, and post solution materials before class.

Exhibit 22 compares a typical online schedule for my course to its on-campus equivalent. While the on-campus course begins with five minutes of class administration, the online course requires ten minutes of class administration. Because we are not all in the same room, I find it necessary to overcommunicate some principles and ensure we have a consistent understanding of the problem. Similarly, I take more time on the mini exercise that begins the class since we will build on it for the entire class session.
The class schedule needed to be reimagined to accommodate the online synchronous format. In particular, the class administration needed to be lengthened, exercises needed to be restructured, and the day’s model needed to be explained earlier in the session.

Since the students had not yet been on campus at MIT, I broke them into two-person groups that analyzed a problem in three minutes. This gave them the opportunity to get to know one another better, and gently ease into the day’s case. In contrast to the on-campus session, I do more of the talking when identifying the issue of the case; basically, I treat this as plot I advance past. While I would never do this on campus, I think this change is necessary online because it gets us to the core analysis faster.

Exhibit 23a shows a Gantt Chart that, on campus, I typically present about 30 minutes into the 65-minute case discussion. At the 50 minute mark, I present Exhibit 23b. By presenting this earlier, the online discussion is more guided, but it still allows students to question if this is the right way to think about the problem. It also ensures we can devote sufficient time to model solution, scenario analysis, and recommendations.
Exhibit 23. The online class presents the session’s model sooner, and in more detail, so that students have time to discuss model solution, scenario analysis, and recommendations in full detail. On campus, (a) is presented 30 minutes into case discussion while (b) is presented 50 minutes into the discussion. Online, both are presented within five minutes of the start of the case discussion.

The third change in the online format is that I posted the solution material in advance. Exhibit 24 shows an analysis that I shared right before class, after students had handed in their analyses.

Exhibit 24 Solution materials were posted before class, but after students submitted their solutions, in order to overcome Zoom’s downscaling of video.
When I teach on campus, right after class I always post my solution approach and any solution approach we develop in class. I still post any approach we create in class soon after class ends. However, I posted my solution in advance so that students could quickly look at the analysis and resolve any questions they might have. It took some effort, but I did not find this unduly influenced the flow of the session, probably because I would pull up student solutions and have them present the salient details.

In the online setting, the TA is critical. In my on-campus classes, the TA’s presence is good to have because they are available if the students have any administrative issues that can be handled by the TA, the students can build rapport with the TA before or after class, and the TA is better able to answer student questions offline, because the TA has experienced the class with the students. In the online class, I need to have the TA because the TA’s role is not a passive observer but an active manager. The TA is the air traffic controller for the class session. First, the TA arranges who talks next, keeping track of who has already talked and who has not yet talked. Second, the TA is able to handle all sorts of small issues (students saying their Wi-Fi is not working, etc.). If I had to be in charge of these issues, it would take me another five or ten minutes in class and I would not do it nearly as well as the TA. The obvious downside of online learning from the TA’s perspective is they work much harder during the class session. The less obvious downside is they remember virtually no content from the online class itself. They are simply too busy managing the participants to pay any attention to the actual material being covered in the class.

After class, I moved to a separate Zoom room. I did not stay in the class’ Zoom meeting because I found some students felt obligated to stay, even though I told them not to. We did have the TA stay behind under the auspices that he could address any administrative questions students might have. I moved to my personal Zoom room and we told students to treat my movement just like they would treat the time right after class. That is, if they would have wanted to come down after class to tell me something, they should pop over to my Zoom room. And just like on campus, some students stopped by after every class, some students never stopped by, and the majority only stopped by when they had a specific issue they wanted to discuss in more detail.

6.3. Lessons Learned

After eight weeks of teaching, these are the most important lessons I came away with:

**Body position directly correlates with teaching energy.** The most important learning is also the most obvious learning. I need to teach in the position that matches my on-campus teaching. Since I stand in the classroom, I need to stand in the studio. There is a direct correlation between my posture, when standing, and my energy teaching the class.

**Everything takes longer in the online synchronous format.** Our on-campus classes are 80 minutes. I cannot teach the same content in the online synchronous format that I teach on campus in the same amount of time. Even with an amazing TA coordinating the student
discussion, there are inherent inefficiencies and delays in the online version. We tightly choreograph student dialogue, but it still takes an extra 5 to 10 seconds on each end. We invariably lose 30 seconds each class when someone fails to unmute. That adds up to minutes for each class.

Equally important, the instructor is not able to read the room and speed up if the class is running behind schedule. The ebb and flow of pacing that is so easy to adjust in person is nearly impossible to manage as seamlessly online. I think I really need 95 minutes online to deliver the on-campus content of an 80-minute class, if I would mimic the on-campus format when teaching online.

**Content coverage and delivery needs to be reimagined.** Related to the previous point, since I am slower in the synchronous online format, I needed to modify my material to achieve the same learning objectives in the same amount of time. While I am as resistant to change as anyone, this was not as hard as it seemed, and I was able to accomplish this without shifting material offline to be completed before class. Instead, I rigorously reevaluated each session’s material to determine what was nice to include but not necessary to include.

I often found myself teaching the session’s material in a different order than I taught it on campus. I started by thinking of the session’s major concepts as items to fit in a knapsack, and then solved the resulting optimization problem to maximize all the items in the knapsack, while still presenting the concepts in a coherent fashion.

**Students are resilient and build a terrific culture.** The students own the classroom experience and improve it. While I knew this would be true, I did not know exactly how it would manifest itself, especially when the students are not in the same location, with much less personal interaction compared to the typical on-campus experience. Over and over again, the students impressed me with how cohesive a culture they formed.

For example, I make a big deal about always staying “in the moment” when in class. Now I rely heavily on the hand-raise feature of Zoom to start students asking and answering questions. After the third class, the students adopted an innovation where each student would lower their virtual hand whenever any other hand was selected. This made every raised hand a conscious decision, and it forced students to stay in the moment, versus pulling the class back to a comment that might be five minutes old. This is only one of many such innovations the students made as the course progressed.

**Making personal connections takes time and effort.** Even with all this great technology, the student experience suffers due to the lack of physical interaction. At some point in most classes, the professor has to cut off or redirect a student who is saying something that is off-topic. It is often a great point, just one not made at the right time; or the point has already been made, and the class would benefit from the discussion ending. In the classroom, the professor can recognize

Electronic copy available at: https://ssrn.com/abstract=3793342
whether the student thought this was a big deal or not. If they did, the professor can catch them on the way out, and make clear it was not a big deal. That really can’t happen in the same way online. When students go back on mute, they are lost in the Zoom gallery, and the pictures are too small to see much facial expression. It dehumanizes the interaction a bit, and that difference matters. We address this by over-communicating with students after class. Again, the TA is an amazing asset here. The TA keeps track of these cases in class so the instructor does not have to go back and look over the video. We can then reach out to the student immediately after class and check in to make sure they are okay.

The instructor cannot fully unplug and focus on teaching. When I teach on campus I turn off all my devices before I begin teaching. When teaching online, I need to keep some communication channel open with the TA so I can be made aware of any technical difficulty that might materialize during the class. The most common example would be if my connection has frozen, or if the audio is out of sync with the video. This is another distraction to monitor during class, and it does take some mental energy that would normally be fully allocated to teaching.

The residential setting causes some anxiety. The reliability of a residential studio is simply not as great as the on-campus infrastructure. This causes anxiety for the instructor and the students. Universities have backup power, and everyone is in the same location, so they all share the same conditions. Having everyone spread apart is a real-world demonstration of Murphy’s Law. Someone is always losing power or suffering from a slow Internet connection. One day, the TA’s apartment building had an electrical fire that took the TA offline for 30 minutes. This does add some anxiety to the teaching process because the delivery system simply is not as robust as the on-campus infrastructure.

Choreography becomes second nature. In the early class sessions I consciously tried to change screen views every few minutes. Since it was all new to me, I invariably made mistakes. More than once, I spoke to an Excel analysis that was not on the screen. As time went on, I got better and better at managing these transitions and within a few weeks they became second nature. Fluidly moving between modalities replicates the on-campus experience, and it makes each transition much more natural.

The on-campus product will improve as a result of synchronous online teaching. An unexpected benefit of synchronous online teaching is that I am confident this will improve my on-campus teaching. The need to tightly choreograph my timing in this online format has forced me to change and improve content that I thought was already good enough. If the material was only going to be delivered on campus, the cost to improve it would not offset the time required. Teaching online forced this reexamination and improvement.

6.4. Did It Work?

Examples of student feedback taken verbatim from the Summer 2020 evaluations include:
▪ (instructor’s) virtual set-up should be replicated by every ...professor - it made the virtual classroom feel very personal and very smooth!
▪ (instructor’s) teaching method is awesome. Himself and his class aside, the mechanics of how he runs the course should be a faculty best practice.
▪ ...amazing job at generating engagement in class.

As one would expect, there is still room for improvement in this online synchronous format:
▪ I think the course did a good job adapting to the digital format although the cases were still not as stimulating as they would have been in person ...Overall excellent course and awesome job and seamless delivery in the digital environment.

Given the effort to reimagine one’s teaching approach, I’m now convinced that many of the benefits of the on-campus course can be achieved in an online-synchronous format.

7. Conclusion

We recognize that a major investment in a home studio and redesigning a course to suit an online-only platform is not for everyone. In fact, the three of us have made such investments for different reasons, with different levels of knowledge, and at different points in our careers. It is unlikely that junior faculty at research-focused universities would, or should, invest heavily in online teaching given their other responsibilities and career objectives.

However, we’ve come to appreciate the incremental nature of progress in online teaching. we have added one component after another to our home studios, improving our platform after testing, tweaking, and occasionally cursing each addition as we struggle to learn how to use it. Our hope in writing this paper and producing our respective YouTube videos is to allow our colleagues to pick and choose among the pieces of technology and teaching methods best suited for their individual teaching styles. For some faculty, simply knowing about how the chat window in Zoom works and encouraging students to use it could dramatically improve their students’ class experience. For those faculty who share our passion for teaching and have the luxury of time and resources, a more substantial investment may be appropriate. In both cases, we hope this guide will lower their cost of entry into the World of Edcraft.

Happy lectures!
A1 Hardware

Let's start with the hardware, which we divide into five categories: audio, video, computing, lighting and background, and miscellaneous. These items are listed in Exhibit 26 (Andrew’s studio), Exhibit 27 (Brian’s studio), and Exhibit 28. Sean Willems’ home studio with labeled components: (a) talking head station; (b) lightboard station. Exhibit 28 (Sean’s studio). The components in each of the photos are labeled with numbers from equipment lists, and we use “(A5)” for component 5 on Andrew’s list, “(B7)” for component 7 on Brian’s list, and “(S13)” for the 13th component on Sean’s list. You can download the spreadsheet “components.xlsx” from our shared Google drive, which contains links to every one of these components from the vendors we used (though we didn’t do a lot of comparison shopping so we have no idea whether we received the best prices). To provide some intuition as to how these parts are connected, we provide a wiring diagram in Exhibit 25 for Andrew’s studio.

![Wiring Diagram for Andrew's Studio](image)

Exhibit 25. Wiring diagram for Andrew’s studio (component labels correspond to those in the equipment list in Exhibit 26).

Please note that these are just the components that we decided to use, and while they work well for our purposes, they need not serve yours. So caveat emptor! You may want to pick and choose from this list and build your studio more gradually, incorporating one component at a time so that you develop sufficient experience before moving on to the next component. Some of them are quite expensive and represent a significant investment. Therefore, if you're looking to give just a few online lectures every now and then, it's absolutely not worthwhile for you to do this. The only reason this kind of investment would make sense is if you're going to be teaching online...
for a period of time and will be using this studio over and over again. We should also emphasize that we have no financial stake in any of these products or companies, nor do we receive any compensation of any sort for product endorsements.

A1.1 Audio

For the microphone, Andrew and Sean use the Sennheiser wireless lavalier microphone (A13a). This is an expensive mic, but it’s phenomenal and we love it. It's wireless, which allows you to move around without any issues, and the sound quality is just excellent. It uses the Sennheiser CHG 2 2-Bay Tabletop Charger (A13b) to charge the mic’s battery pack.

Brian uses the Shure SM7B Cardioid Dynamic Microphone (B1), and the sound is simply fantastic. Both Andrew and Sean have audio envy when they listen to Brian on Zoom calls because his sound is crystal clear, clean, and rich. Unless you spend time listening to enough online content, you won’t fully appreciate just how remarkable this microphone is. Of course, the main downside is that you have to speak into it, so it won’t work if you want to move around. But for any kind of stationary lecture style where you don’t mind having a big microphone in front of you, this is the way to go.

The microphone needs to be connected to your computer, and there are two ways to do this. Sean uses the Sound Devices USBPre 2 Microphone Interface for Computer Audio (S6), which is a preamplifier that sits between the microphone and the computer. Its audio meters are very easy to read and make setting the gain totally idiot proof. Andrew and Brian use a different product, the TC-Helicon GoXLR Audio Mixer (A10, B3), which controls all the various different audio components of your online lecture, including the wireless mic, your computer sounds, and creating special effects like the “Voice of God” or an echo chamber. It also allows you to control the volume of different sources individually, so you can show your class a video clip that contains sounds, then narrate what the students are seeing by reducing the volume of the video while maintaining your mic volume.

The Sennheiser IE 500 Pro In-Ear Monitor (A20) is a set of in-ear monitors, which allow you to hear exactly what your audience is hearing. This is particularly useful for avoiding “Zoom voice,” the hoarseness that comes from straining your voice when talking to a computer or TV screen all day and unconsciously raising your voice to project the sound towards the screen. It took us a while to figure out why we were getting Zoom voice—and some of us were better at avoiding this behavioral bias—but once we started using in ear monitors, this behavioral tendency was greatly reduced.
A1.2 Video

We use several different webcams, most of which are digital single-lens reflex cameras (DSLRs) originally made for digital photography that have been repurposed as webcams, and they perform admirably. Andrew and Sean both use the Canon EOS RP DSLR camera (A6, S13), and Andrew has also used the Lumix G7 (a Panasonic brand and a favorite of YouTube vloggers because of its quality and price). Sean also uses the newer Canon C70 Cinema camera (S12), that has more features specifically designed for video. However, Brian chose to make the investment in a professional videocamera, the Sony FDR-AX1 Digital 4K Video Camera Recorder.

To turn the webcam output into a digital signal that your computer can understand, you’ll need some sort of conversion device. Andrew and Brian use the ATEM Mini HDMI livestream switcher (A5, B7). This is a very expensive component that does a lot more than just convert analog video signals into digital. For example, you can connect multiple cameras into this device and switch from “Camera 1” to “Camera 2” with a touch of a button. This is ideal if you want to broadcast two different views of the subject, or if you want a shot of yourself and then one of your audience and be able to toggle between the two instantaneously. However, for doing online lectures, this is probably overkill. You can easily get by with an El Gato Cam Link 4K device that Sean uses (S16)—currently $112.25 on Amazon—which resembles an oversized USB thumb drive. You connect your webcam to this device via the appropriate video cable, the device plugs into a USB port on your computer, and you’re good to go.

The Manfrotto 290 XTRA Aluminum 3-Section Tripod with 3-Way Head (A4a) is the tripod for the camera. On top of the tripod sits a remote control pan/tilt head (A4b). With a solo operation, it’s very time-consuming to adjust your webcam’s position because you have to run back and forth between your desk and the camera multiple times before you find the perfect angle. With this device, you can move the camera up/down and left/right from your desk using the wired remote control, allowing to you point the camera exactly where you want it in a matter of second.

For showing documents and annotating them as you narrative, the IPEVO VZ-R document camera (A12) works well. For certain mathematical derivations, we’ll just put a blank piece of paper under the document camera and using a black magic marker to write the derivations as we narrate the specific terms we’re writing. Although you could easily present these same derivations in a nicely formatted slide, there’s something about handwriting mathematical expressions term by term that gives students an extra sense of comfort and understanding. Sean has a more elaborate setup—he uses the Canon EOS RP as his document camera (S13)—because he spends quite a bit of time writing content during lectures and wants more flexibility in creating this shot.

We each use different monitors and the number and sizes depend on our individual setups. Brian has a smaller space for his home studio so his monitors are relatively close to him and are standard-sized computer monitors. Sean’s studio is much larger hence his main monitor is the
82” Samsung RU9000 Series 4K UHD LED LCD TV (S17). Andrew’s monitor is placed about 20 feet from where he stands, so a Sony 65” TV (A2a) is sufficient.

We recommend purchasing two additional monitors (A16b), which may seem excessive but they’ll provide tremendous convenience and greatly reduce the mistakes you’re likely to make when switching sources, closing and opening applications, and sharing screens. One of these monitors will serve as the main screen for your computer, and the other monitor will be used to project your Powerpoint slides in presentation mode, and for sharing your screen in Zoom.

Sean makes great use of the Height Adjustable Lightboard System, Extra Large (95”) (S21) produced by Revolution Lightboards. This is not an easy item to move, so getting it to his second floor studio required hiring glass movers. Every detail of the design is thought through, so from the instructor’s perspective this is plug-and-play, which is wonderful and a huge timesaver. The Lightboard Control Center (S22) takes care of all the hardware required to operate the lightboard with or without a computer, allowing the lightboard to look like any other camera source in OBS.

A1.3 Computing

All three of us have learned the hard way that laptops just aren’t powerful enough for broadcasting an online lecture with all the functionality that we need, so we’ve all opted for desktops of different kinds. Andrew’s desktop computer is a ThinkMate VSX R5 540X1 workstation (with monitor, keyboard, mouse) (A16), and is the most expensive item on his list. Part of the reason is that it’s built not only for online lectures, but also for video editing and research computing (he conducts Monte Carlo simulations, maximum likelihood estimation, and machine learning on it). It has 256Gb of RAM, a 2Tb SSD boot drive, a 4Tb SSD drive for user content, an NVIDIA Quadro RTX 6000 graphics card with 24Gb of memory, and is liquid-cooled so it’s totally silent (no fan noise whatsoever). Sean uses a Mac Pro with a 3.2 GHz 16-Core Intel Xeon W processor, 96Gb of RAM, an AMD Radeon Pro Vega II graphics card with 32Gb of memory, and a 1Tb SSD drive. Brian uses an NZXT gaming computer that’s custom-built to comparable specifications.

The El Gato Stream Deck XL (A1, B14, S16) is an indispensable device from the gaming community that allows you to assign multiple keystrokes to a single button, and the XL version of this device has four rows of eight buttons each, giving you 32 buttons that can be preprogrammed for all sorts of functions. In fact, you have many more buttons available because you can assign one button to bring you to an entirely new “page” of 31 buttons (because you need one button to bring you back to the previous page), and you can have multiple pages of buttons. The Stream Deck’s software is integrated with several other streaming software platforms as well as OBS. This allows you to assign one button to the OBS scene with a full-sized image of yourself in the middle of the frame, and second button to the OBS scene showing your powerpoint slide in the entire frame and a smaller-sized image of yourself in the lower right-hand corner, “weatherman”
style. Switching from one scene to the next is literally at the touch of a button, and is instantaneous. This feature, more than any other, is what students comment on when acknowledging the “higher production quality” of our online lectures, and is one of the most satisfying features of a home studio.\footnote{Not only are the Stream Deck’s buttons reconfigurable through its easy-to-use software interface, but the images on the buttons are also customizable. All that’s needed is an image file (.jpg, .png, etc.), but El Gato provides a web app that allows you to design your own button illustration. We have each spend way too much time creating just the right image for buttons on our Stream Deck!} You know this component must be really important if all three of us have it.

Even though you can hear sound from your computer via the in-ear monitors that we recommended above, you’ll also want speakers for those occasions when you’re not lecturing and you don’t wish to wear the in-ear monitors. We love the sound of good computer speakers (A15, S1). The Bose speakers (A15) have the added feature of a very convenient on/off switch and volume control that’s connected to one of the speakers via a two-foot cable, allowing you to place it next to your keyboard so you can control it easily while lecturing.

Finally, for those users who like to annotate their Powerpoint slides while they lecture, the Wacom Intuos Pro Graphics Tablet (A14) is the appropriate input device. We don’t use this device very much because we find that the document camera provides a more dynamic platform for written input, but this is clearly a matter of taste.

## A1.4 Lighting and Background

Lighting is one of the most often neglected components in home studio setups, yet we believe it’s one of the most critical factors in creating a professional-looking online presence. Most video experts recommend using three light sources so as to be able to eliminate unwanted shadows and provide illumination for most setups. The NanLite Forza 60 LED Monolight (A3a) is a very compact but bright light and, when paired with the NanLite Forza 60 Softbox (A3a), provides soft diffuse light that doesn’t create shadows. The GVM 800D-RGB LED Studio 3-Video Light Kit (A3b) provides three very bright LED panels (of which you only need two) to provide more illumination for your set.

The ProMaster 10x20’ Solid Backdrop with the ProMaster Telescoping Background Stand Set (A7) is an excellent green screen that’s wide enough to accommodate virtually any shot you’re likely to need (this is especially important if you’re using the standard 16:9 aspect ratio for your broadcast, which is standard for HD video broadcasts). A green screen is essential for creating the “weatherman” look, allowing you to replace your background which pretty much any image or video you choose. Although Zoom does have a “virtual background” feature that also allows you to replace your background, it doesn’t work nearly as well without a green screen. Also, this Zoom feature adds an extra computational burden on Zoom, which can cause video lags and...
other glitches, so we’ve found that inserting a virtual background through OBS and a green screen is much more stable and visually convincing.

A1.5 Miscellaneous

The final pieces of miscellaneous equipment include a desk from which to deliver your lectures, and then a few other important accessories.

For our desk, we wanted something that could accommodate both seated positions (for online meetings) and standing positions (for delivering online lectures), and was heavy-duty enough to hold two monitors as well as the workstation, two monitors, the ATEM mini, GoXLR, and Stream Deck. Our recommendation is the Uplift V2 Commercial Desk, an incredibly solid piece of furniture that allows the user to change the height at the touch of a button. This desk comes in many configurations and work surfaces, with lots of options including monitor arms, cable management systems, powerstrips, etc. The only downside is its heft—the desk came in several large cartons and requires two people of reasonable strength to move into your studio space. From our personal experience, it’s possible for one person to assemble it, but once assembled, it’s still a good idea to have two people to maneuver it into its final position.

Any type of presentation will require a presentation remote, and we recommend the Logitech Spotlight (A17) instead of the more standard laser-pointer remote. The reason is simple: you can’t use a laser pointer for an online lecture, but the Logitech Spotlight works perfectly, creating a bright circle on a dimmed powerpoint slide that moves as the remote is moved while the highlight button is pressed and held.

For occasions where you want to advance slides or press certain keystrokes without using your hands, a Three-Pedal Foot Switch (A9) is the solution. When would you want to do this? One example is if you’re pre-recording a videoclip and wish to use Powerpoint slides like a teleprompter, in which case you need to advance the slides as you finish reading one slide and are ready for the next. Another example is if you’re interviewing a guest speaker and you’ve placed your questions and notes onto Powerpoint slides that you need to advance. A third example is the occasional need to locate your mouse pointer, which can require quite a bit of fumbling if you have three screens and are in the midst of a conference presentation or lecture. Just program one of the foot pedals to move your pointer to a specific location (which can be done with utilities like AutoHotKey on a Windows machine and Keyboard Maestro on a Mac), and then assign that shortcut to the footpedal using the interface that comes with it.

This footswitch, and many other components we’ve listed, are connected to your computer via USB ports, but most computers won’t have enough ports to accommodate all of these devices, so you’ll first need to define a keyboard shortcut to move your pointer to a specific location (which can be done with utilities like AutoHotKey on a Windows machine and Keyboard Maestro on a Mac), and then assign that shortcut to the footpedal using the interface that comes with it.

18 You’ll first need to define a keyboard shortcut to move your pointer to a specific location (which can be done with utilities like AutoHotKey on a Windows machine and Keyboard Maestro on a Mac), and then assign that shortcut to the footpedal using the interface that comes with it.
so we recommend adding more. The Sabrent 60W 10-Port USB 3.0 Smart Charging Ports (A8) is a good choice both because of the number of ports as well as the indicator lights and on/off switches for each port.

If you’re in an environment where power can be interrupted, or if there are regular voltage spikes—which are the enemy of audio/visual equipment, not to mention expensive computers—we highly recommend getting an uninterruptible power supply. We chose the APC Smart-UPS 1500VA LCD 120V with SmartConnect (1000 Watts Output) (A18) in our CSAIL studio.

You'll also need a number of cables and connectors of various types (A19), depending on your setup and the distances of the components. If you decide to incorporate all of the components we listed into your home studio, you’re going to learn the differences between USB-A, USB-B, and USB-C connectors, and this is important because you’re going to need to buy additional cables to connect them all. Although each of your components will typically come with its own cable, you’ll run into situations where that cable isn’t long enough so you’ll need to buy extenders. However, you won't know what cables you’ll need until after you set up your system and decide where each component is best situated. Therefore, we recommend putting together your system first and making sure it works the way it was intended, and only after the setup is finished do you decide what kinds of extenders you need.

### A2 Software

Online teaching involves a variety of software components which we group into the following categories:

- Presentation content: Powerpoint, Keynote
- Computation: Excel
- Video recording and live streaming: OBS Studio
- Video editing: Adobe Premiere Pro
- Audio editing: Avidemux, Audacity
- Video special effects: Adobe Premiere Pro
- Videoconferencing: Zoom
- Miscellaneous Utilities: AutoHotKey, Keyboard Maestro, Snaz

We assume that readers are already familiar with presentation content and computation software, so we focus instead on the remaining software in this section.

#### A2.1 OBS Studio

In the same way that a Hollywood film studio brings together different elements to produce a movie—actors, writers, director, set designers, and so on—OBS Studio is a powerful piece of
software that brings together all the elements that make up an online lecture. Learning how to use OBS may seem daunting at first—at least, it was to us—but we found that after just a few YouTube tutorials, we were able to get the hang of it.

While OBS has many features and, therefore, many layers of complexity, the basic idea is straightforward: OBS takes various inputs—called “sources”—such as an audio feed (from your microphone, for example), a video feed (from your webcam or document camera), an image (such as a virtual background), or a display (like a computer monitor), and then combines them into a “scene.” A scene is exactly what it sounds like using the filmmaking analogy: a particular arrangement of sources. For example, one scene might be you (the webcam) in front of a virtual background of a classroom. A second scene might be you in front of a powerpoint slide show. And a third scene might be a split screen with you on the left side and the document camera on the right side. With each scene, you have total flexibility to control the position and size of each source, just as if you were a film director responsible for deciding how to shoot a car chase or a love scene.

Once the scene is created, OBS can send it into a “virtual webcam” that’s recognized by Zoom and once selected in Zoom, voila, your scene now appears to the other participants. The reason that more and more faculty are starting to use OBS is the tremendous range of control it gives us in creating different scenes quickly, easily, and with much higher quality than simply looking into a laptop webcam.

In fact, the ability of OBS to combine and process all these sources is one of the reasons we suggest using a dedicated desktop for online teaching. Most general-purpose laptops simply aren’t powerful enough to do all the things we might want to do in an online lecture. Of course, if you don’t plan to use more than a couple of sources and aren’t as concerned about occasional audio or video lags, then a laptop may work just fine, which is why we’ve recommended taking an incremental approach to building your home studio over time.

For editing video, I use a different set of software. It turns out that Windows 10 has a very good editor built into it, the Windows 10 Video Editor. If you want to be a little bit more professional, Adobe Premiere Pro is excellent. I also use Avidemux and Audacity to edit the sound.

A2.2 Zoom

After OBS, the second-most important piece of software is, of course, your online teaching platform, and we use Zoom (although Brian has recently switched over to YouTube for his livestreamed classes, so please check out his case study and videos to see how that platform

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19 The exception is dedicated gaming laptops, which are optimized for graphics and, in some cases, livestreaming, but most faculty aren’t likely to own an Alienware m15 R3 Gaming Laptop with an Nvidia GeForce RTX 2080 Super 8GB GDDR6 graphics card.
compaes). Because all the hard work in putting together the different components that make up a lecture have already been taken care of in OBS, there’s not a whole lot you need to do with Zoom regarding your streaming content (there is, of course, a lot to do with Zoom’s other features such as breakout rooms, the chat window, and so on, but we’ll get to that shortly).

Using OBS is especially useful for playing videoclips for your class. Rather than using Zoom’s screen-share feature to show the videoclip, you can bring the clip into OBS, position it exactly where you want (e.g., to take up the entire screen, or only part of it so you can show your students how you’re reacting to the video as they and you watch the clip, etc.). Because OBS send the combined videostream into Zoom, there’s very little lag and far fewer skipped frames than if you used screen-share, even with the “optimize for video sharing” box checked. As long as the videoclip plays smoothly on your computer, OBS will provide an equally smooth stream into Zoom.

We also recommend using polls in Zoom so as to increase student interaction and participation. For any given 90-minute lecture, we’ll use two or three polls in which students are asked specific questions either about themselves (e.g., “I plan to pursue a career in healthcare after graduation: (1) yes; (2) no; (3) undecided”), or about the subject of the lecture (e.g., “The most I would pay for investment A is: (1) $1,000; (2) $2,000; (3) $3,000; (4) $4,000”). After the poll closes, Zoom allows you to show the results to the entire class, and then we spend a few minutes discussing those results.

We also use breakout rooms to allow students to interact with each other. One very useful Zoom feature is the ability to pre-assign breakout rooms of any size, allowing you to group students according to specific objectives such as maximizing the number of first-time meetings between students in each breakout room (which Andrew used in his online healthcare finance course), or maximizing the diversity of students’ prior work experience within each room, and so on. The only drawback with this feature is that currently it’s only possible to have one set of breakout assignments per Zoom session.

Two other components of Zoom that deserve highlighting are the use of blue hands for students who want to ask questions, and the use of the chat window so students can interact with each other. Both features facilitate student engage with the instructor and, more importantly, with each other. In particular, the “wisdom of crowds” is a powerful source of information for any class with more than a handful of students, not to mention the camaradie that can arise spontaneously if the right “chat culture” is established at the outset. Because the instructor is typically unable to monitor the presence of raised blue hands or chats that should be brought into class discussion, the role of the teaching assistant during class is much more important in this context than for in-person lectures.
There is one issue with Zoom that instructors should be aware of, and it has to do with whether one should use Zoom’s screen-share function to show slides. The “weatherman” approach that Andrew favors, or the newscaster scene that Brian uses, eliminates the need to share your screen via Zoom. However, some—but not all—of our students reported a strange and frustrating phenomenon: when we don’t use screen sharing, the resolution of our image seems to decline, to the point where it becomes hard to read smaller-font text on our slides. With screen-shared slides, the resolution seems higher and the slides appear clearer.

This is no optical illusion. After a bit of investigation, we discovered that Zoom does seem to offer higher-resolution with screen-shared content than a typical Zoom session, and this policy seems to be institution-wide. Our assumption is that, to preserve bandwidth, Zoom keeps the resolution as low as possible subject to some acceptable lower bound on the legibility of its stream. Given that screen-sharing often involves displaying text of varying sizes on a screen, the legibility constraint would call for higher resolution in these cases, hence the difference. This becomes most problematic for students with lower bandwidth connections, so whether your students complain about this issue depends to a significant degree on where they’re located and what kind of internet service they have.

Apart from asking Zoom to change the resolution on your account, the only two solutions we’ve come up with are: (1) to increase the font size used on your slides; or (2) to use screen-share mode rather than the “weatherman” format. We hope Zoom will be able to address this issue in a future update.

### A2.3 Audio/Video Editing Software

So far, the software packages we’ve considered are meant primarily for delivering synchronous lectures. There are several other useful programs for preparing asynchronous lectures.

OBS does have a very useful recording function; in fact, that’s what all three of us used in preparing our YouTube videos of our online teaching setups.

After recording raw footage in OBS, we used several programs to edit that footage to produce the final versions of our videos. Adobe Premiere Pro, which is available for both Windows and Mac users, is our preferred choice for video editing, given its flexibility and ease of use. Mac users may also want to consider iMovie, which is used by many professional videographers, and there is also a Windows version.

For editing audio tracks, there are two excellent programs, both free and open-source, that we’ve used extensively: Audacity and Avidemux. Avidemux allows users to edit both video and audio, and Andrew has used it extensively to fix a glitch in recordings made with his setup: a constant delay of 250 milliseconds between his audio and video tracks. Although this sounds small, it’s...
very noticeable and annoying when you’re watching a video with slightly mistimed audio. Avidemux provides a super-easy solution to this problem.

### A2.4 Miscellaneous Utilities

There are several helpful software packages that we use to support our synchronous online teaching, most of which are free. A countdown timer like **Snaz** is very flexible and is easily incorporated into OBS to create a screen that displays a digital timer which counts down the number of hours, minutes, and seconds to classtime.²⁰

**AutoHotKey** is a remarkably powerful free keyboard macro utility for creating shortcuts to accomplish a wide range of tasks. One example is a macro that moves the mouse pointer to the middle of a specific monitor. With multiple monitors, it can sometimes be a challenge to locate your pointer, especially if you’re in the midst of a lecture or Zoom meeting, so having a keyboard shortcut that can be assigned to either a footpedal or a Stream Deck button is essential for being able to navigate your computer under stress conditions! AutoHotKey offers a scripting language for creating these shortcuts and then the ability to compile these scripts into executable images that can then be run by many applications, including via the command line. For the Mac, there’s a more user-friendly proprietary utility called **Keyboard Maestro** that essentially allows you to “record” a sequence of keystrokes and then assign that sequence to a hotkey.

To turn your smartphone into a webcam, **OBS.ninja** is a free web application that’s easy to use and works seamlessly with OBS so you can incorporate a second webcam source in your online lectures. This is what Andrew used to film his backup studio in his first video.²¹

²⁰ An excellent tutorial for how to create a countdown timer scene in OBS is provided by Pete Wilkins’ #GamingCareers YouTube channel at [https://www.youtube.com/watch?v=6NE3FDxJ_h0](https://www.youtube.com/watch?v=6NE3FDxJ_h0).

## A3 Equipment List (Andrew Lo’s Studio)

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<td>A11</td>
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</tr>
<tr>
<td>Heavy Duty Casters for two-leg and four-leg desks</td>
<td>Uplift Desk</td>
<td>A11</td>
<td>$49.00</td>
</tr>
<tr>
<td>UPLIFT Range Dual Monitor Arm - Black</td>
<td>Uplift Desk</td>
<td>A11</td>
<td>$139.00</td>
</tr>
<tr>
<td>Logitech Spotlight Presentation Remote</td>
<td>Amazon</td>
<td>A17</td>
<td>$102.50</td>
</tr>
<tr>
<td>Three-Pedal Foot Switch</td>
<td>Amazon</td>
<td>A9</td>
<td>$39.99</td>
</tr>
<tr>
<td>Sabrent 60W 10-Port USB 3.0 Smart Charging Ports</td>
<td>Amazon</td>
<td>A8</td>
<td>$37.98</td>
</tr>
<tr>
<td>APC Smart-UPS 1500VA LCD 120V with SmartConnect (1000 Watts)</td>
<td>Amazon</td>
<td>A18</td>
<td>$377.99</td>
</tr>
<tr>
<td>Cables, depending on your setup and distances, but you’ll need a number</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>of cables of various types of connectors</td>
<td>Amazon,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B&amp;H</td>
<td>A19</td>
<td>$200.00</td>
<td></td>
</tr>
</tbody>
</table>

Exhibit 26. Andrew Lo’s studio at MIT CSAIL with labeled components.
## A4 Equipment List (Brian Stevens’ Studio)

<table>
<thead>
<tr>
<th>Component</th>
<th>Source</th>
<th>Diagram #</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Audio</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shure SM7B Cardioid Dynamic Microphone</td>
<td>Amazon</td>
<td>B1</td>
<td>$399.00</td>
</tr>
<tr>
<td>RODE PSA 1</td>
<td>Amazon</td>
<td>B2</td>
<td>$99.00</td>
</tr>
<tr>
<td>GoXLR Audio Mixer</td>
<td>Amazon</td>
<td>B3</td>
<td>$498.98</td>
</tr>
<tr>
<td>Cloud Microphones Cloudlifter CL-1 Mic</td>
<td>Amazon</td>
<td>B4</td>
<td>$149.00</td>
</tr>
<tr>
<td><strong>Video</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sony FDR-AX1 Digital 4K Video Camera Recorder</td>
<td>B&amp;H</td>
<td>B5</td>
<td>$2,599.95</td>
</tr>
<tr>
<td>Sachtler Ace Fluid Head with 2-Stage Aluminum Tripod &amp; On-Ground Spreader</td>
<td>B&amp;H</td>
<td>B6</td>
<td>$712.50</td>
</tr>
<tr>
<td>ATEM Mini HDMI livestream switcher</td>
<td>B&amp;H</td>
<td>B7</td>
<td>$295.00</td>
</tr>
<tr>
<td>Huion KAMVAS GT-191 V2</td>
<td>Amazon</td>
<td>B8</td>
<td>$369.00</td>
</tr>
<tr>
<td>Dell D3218HN 31.5&quot;</td>
<td>Staples</td>
<td>B9</td>
<td>$219.99</td>
</tr>
<tr>
<td>Sony Alpha a6400</td>
<td>Best Buy</td>
<td>B10</td>
<td>$899.99</td>
</tr>
<tr>
<td>LG - 34WL500-B 34&quot; IPS LED UltraWide</td>
<td>Best Buy</td>
<td>B11</td>
<td>$299.99</td>
</tr>
<tr>
<td>Sigma 30mm F1.4 Contemporary DC</td>
<td>Amazon</td>
<td>B12</td>
<td>$278.00</td>
</tr>
<tr>
<td><strong>Computing</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NZXT Custom Build</td>
<td>NZXT</td>
<td>B13</td>
<td>$4,503.86</td>
</tr>
<tr>
<td>Elgato Stream Deck XL</td>
<td>Amazon</td>
<td>B14</td>
<td>$249.99</td>
</tr>
<tr>
<td>Elgato Stream Deck</td>
<td>Amazon</td>
<td>B15</td>
<td>$149.99</td>
</tr>
<tr>
<td><strong>Lighting and Background</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elgato Key Light Air</td>
<td>Amazon</td>
<td>B16</td>
<td>$129.99</td>
</tr>
<tr>
<td>Neewer 2 Packs S200 5600K</td>
<td>Amazon</td>
<td>B17</td>
<td>$159.99</td>
</tr>
<tr>
<td>Elgato Green Screen MT</td>
<td>Amazon</td>
<td>B18</td>
<td>$159.99</td>
</tr>
<tr>
<td><strong>Miscellaneous</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cables, depending on your setup and distances, but you’ll need a number of cables of various types of connectors</td>
<td>Amazon, B&amp;H</td>
<td></td>
<td>$200.00</td>
</tr>
<tr>
<td>utechsmart-us-d16400-gm-venus-usb-wired mouse</td>
<td>Newegg</td>
<td>B19</td>
<td>$45.99</td>
</tr>
<tr>
<td>VELOCIFIRE TKL01 Mechanical Keyboard tkl 87-Key</td>
<td>Newegg</td>
<td>B20</td>
<td>$82.99</td>
</tr>
<tr>
<td>Mario Mug</td>
<td>Nintendo</td>
<td>B21</td>
<td>Priceless</td>
</tr>
</tbody>
</table>

Exhibit 27. Brian Steven’s home studio with labeled components.
## A5  Equipment List (Sean Willem’s Studio)

<table>
<thead>
<tr>
<th>Component</th>
<th>Source</th>
<th>Diagram #</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shared Components</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A2+ Home Music System w/ Bluetooth APTX</td>
<td>Audioengine</td>
<td>S1</td>
<td>$269.00</td>
</tr>
<tr>
<td>APC Back-UPS Pro BR1500MS Battery Backup &amp; Surge Protector (Sinewave)</td>
<td>B&amp;H</td>
<td>S2</td>
<td>$203.99</td>
</tr>
<tr>
<td>Mac Pro (3.2 GHz 16-Core Intel Xeon W, 96 GB 2933 MHz DDR4 AMD Radeon Pro Vega II 32 GB 1 TB)</td>
<td>Apple</td>
<td>S3</td>
<td>$10,869.00</td>
</tr>
<tr>
<td>Pro Display XDR Standard Glass</td>
<td>Apple</td>
<td>S4</td>
<td>$4,599.00</td>
</tr>
<tr>
<td>Sennheiser AVX-MKE2 SET Digital Camera-Mount Wireless Omni Lavaliere Microphone System (1.9 GHz)</td>
<td>B&amp;H</td>
<td>S5</td>
<td>$899.00</td>
</tr>
<tr>
<td>Sound Devices MixPre-3 II 3-Channel / 5-Track Multitrack 32-Bit Field Recorder</td>
<td>B&amp;H</td>
<td>S6</td>
<td>$710.00</td>
</tr>
<tr>
<td><strong>Talking-Head Station Components</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aputure Amaran AL-HR672W Daylight LED Video Light with Remote</td>
<td>B&amp;H</td>
<td>S7</td>
<td>$278.00</td>
</tr>
<tr>
<td>Aputure Light Dome II (34.8&quot;)</td>
<td>B&amp;H</td>
<td>S8</td>
<td>$488.00</td>
</tr>
<tr>
<td>Aputure Light Dome Mini II (21.3&quot;)</td>
<td>B&amp;H</td>
<td>S9</td>
<td>$219.00</td>
</tr>
<tr>
<td>Aputure Light Storm C300d Mark II LED Light Kit with Gold Mount Battery Plate</td>
<td>B&amp;H</td>
<td>S10</td>
<td>$129.00</td>
</tr>
<tr>
<td>Canon EOS C70 Cinema Camera (RF Lens Mount)</td>
<td>Hunt’s</td>
<td>S11</td>
<td>$1,099.00</td>
</tr>
<tr>
<td>Canon EOS RP Mirrorless Digital Camera with 24-105mm f/4-7.1 Lens</td>
<td>B&amp;H</td>
<td>S12</td>
<td>$5,499.99</td>
</tr>
<tr>
<td>Canon RF 24-70mm f/2.8L IS USM Lens</td>
<td>B&amp;H</td>
<td>S13</td>
<td>$2,299.00</td>
</tr>
<tr>
<td>Elgato Cam Link 4K</td>
<td>B&amp;H</td>
<td>S14</td>
<td>$119.99</td>
</tr>
<tr>
<td>Elgato Stream Deck XL</td>
<td>B&amp;H</td>
<td>S15</td>
<td>$249.99</td>
</tr>
<tr>
<td>Samsung 82&quot; - RU9000 Series - 4K UHD LED LCD TV</td>
<td>Costco</td>
<td>S16</td>
<td>$1,699.99</td>
</tr>
<tr>
<td>Standing Desk Frames: Single Motor EC1/EN1</td>
<td>Flexispot</td>
<td>S17</td>
<td>$269.99</td>
</tr>
<tr>
<td><strong>Lightboard Station Components</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LG 55&quot; BIPUA 4K Ultra HD Smart OLED TV</td>
<td>Amazon</td>
<td>S18</td>
<td>$1,749.00</td>
</tr>
<tr>
<td>Canon EOS C70 Cinema Camera (RF Lens Mount)</td>
<td>Hunt’s</td>
<td>S19</td>
<td>$5,499.99</td>
</tr>
<tr>
<td>Canon RF 24-70mm f/2.8L IS USM Lens</td>
<td>B&amp;H</td>
<td>S20</td>
<td>$2,299.00</td>
</tr>
<tr>
<td>Elgato Stream Deck XL</td>
<td>B&amp;H</td>
<td>S21</td>
<td>$249.99</td>
</tr>
<tr>
<td>Height Adjustable Lightboard System, Extra Large (95&quot;)</td>
<td>Revolution Lightboards</td>
<td>S22</td>
<td>$8,490.00</td>
</tr>
<tr>
<td>The Lightboard Control Center-Standalone</td>
<td>Revolution Lightboards</td>
<td>S23</td>
<td>$1,890.00</td>
</tr>
</tbody>
</table>

Exhibit 28. Sean Willems’ home studio with labeled components: (a) talking head station; (b) lightboard station.
A6 Useful Links to Online Resources

There are so many sources that we rely on regularly for designing, installing, configuring, troubleshooting our studios that it's hard to provide an exhaustive set of helpful links. We highly recommend consulting YouTube for any issue you run into, and chances are you’ll find exactly the right information within 15 minutes of diligent searching. The following are links to resources that we’ve found invaluable:

- Andrew Lo’s home studio setup: https://youtu.be/jaFHhQktJiw
- Andrew Lo’s video on teaching 15.482 online: https://youtu.be/hmGV_c-kriU
- Sean Willems' home studio setup: https://bit.ly/2Lb7j9b
- Brian Stevens' home studio setup: https://www.youtube.com/watch?v=IrP-ObAMLZI&feature=youtu.be and how he uses it to teach undergraduate stats: https://www.youtube.com/watch?v=P5N9_hvc9AI&feature=youtu.be
- Hardware spreadsheet, and other files can be downloaded from: https://drive.google.com/drive/folders/1p31Za-YuU7AbGxiPjrs0N-oAc2uSchiM?usp=sharing
- To edit Andrew’s powerpoint file, you'll need to install The Bold Font (used in the first slide only), which can be obtained at https://www.dafont.com/the-bold-font.font).
- To create Andrew’s title slide with video behind cut-out letters: https://www.youtube.com/watch?v=PuSRHUehtCo
- To download OBS Studio: https://obsproject.com/
- Great OBS tutorial: https://www.youtube.com/watch?v=ySENWFpkL7c
- Additional OBS advice: https://www.youtube.com/watch?v=CvzAogXtREw
- To set up the Canon EOS RP as a webcam: https://www.youtube.com/watch?v=y_2A0PYLNco&t=135s
- To set up the GoXLR: https://www.youtube.com/watch?v=G2O_f5AGg7Q
- To set up the ATEM Mini Pro: https://www.youtube.com/watch?v=AYjogcP-GXY
- To create a countdown timer: https://www.youtube.com/watch?v=6NE3FDxJ_h0
- To make your own stinger transition: https://www.youtube.com/watch?v=wGntVBSnA8Q
- Patrick Winston's "How to Speak": https://www.youtube.com/watch?v=Unzc731iCUY
- Jay Phelan's setup for producing lectures to be viewed asynchronously: https://www.youtube.com/watch?v=znzECF9V-h4&t=96s
- GamingCareers Youtube channel (great resource for tutorials on all things audio/video/livestreaming): https://www.youtube.com/channel/UClx4eJ_EP9MJdz19JUjKD1w
- EposVox Youtube channel (another great source of information for livestreaming tech): https://www.youtube.com/user/EposVox
A7 Sample Zoom Chat Window Transcript from 15.482

The following is a portion of the complete transcript of the chat window for lecture 12 of 15.482 Fall 2020. The topic of the lecture was “Pricing, Insurance, and Ethics”. The blue boxes provide groupings of the chats according to the topics being covered in lecture at the corresponding times.

Current lecture topic: general inflation vs. biomedical inflation

Current lecture topic: what’s the value of human life and how is this related to how drugs are priced?

Current lecture topic: ethics, and the modern version of the trolley car ethical dilemma
A8  15.482 Fall 2020 After-Class Evaluation (implemented in Qualtrics)

1. Please rate the performance of all members of your breakout session (and make sure to include yourself so as to preserve the anonymity of this survey):

<table>
<thead>
<tr>
<th>Rating</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition</td>
<td>Effective</td>
<td>Ineffective</td>
<td>Absent</td>
</tr>
<tr>
<td>Student #1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student #2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student #3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student #4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student #5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student #6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Please rate the performance of the instructor:

<table>
<thead>
<tr>
<th>Rating</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition</td>
<td>Ineffective</td>
<td>Somewhat Ineffective</td>
<td>Neutral</td>
<td>Somewhat Effective</td>
<td>Effective</td>
</tr>
</tbody>
</table>

3. Please rate the performance of the speaker(s):

<table>
<thead>
<tr>
<th>Rating</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definition</td>
<td>Ineffective</td>
<td>Somewhat Ineffective</td>
<td>Neutral</td>
<td>Somewhat Effective</td>
<td>Effective</td>
</tr>
<tr>
<td>Speaker #1</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Speaker #2</td>
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</tr>
<tr>
<td>Speaker #3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Do you have any comments or suggestions for improving the class? Every suggestion will be reviewed and considered, though we may not be able to implement them all.
References


Willems, Sean, 2020, Designing A Home Studio For Online Synchronous Teaching.