$V = \sigma$

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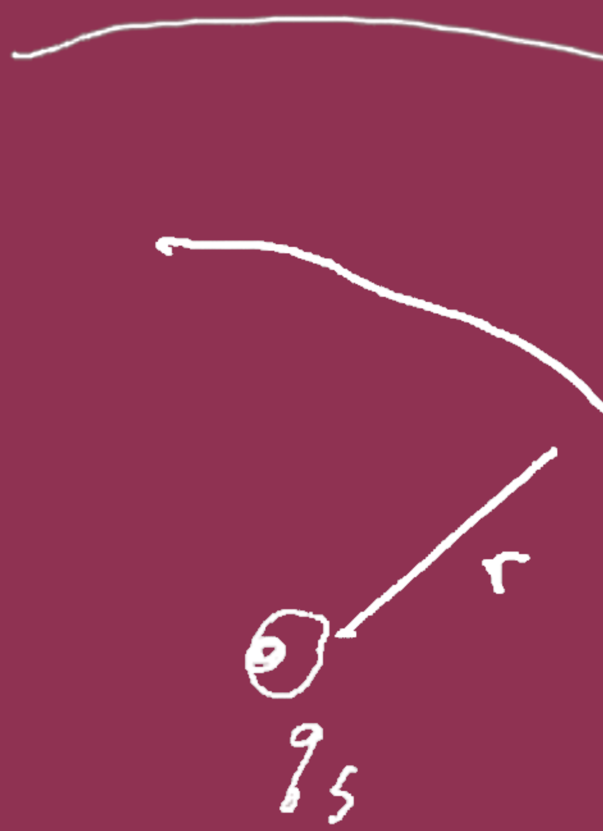

2)

$$dq = \rho\, dV$$
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$$\ln\left(\frac{a+b}{a}\right) = \ln\left(1 + \frac{b}{a}\right)$$

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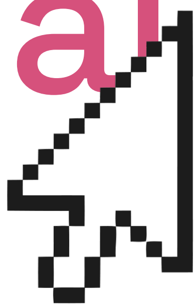
Remotely Educational



Teaching physics in the age of Zoom.

by Sandi Miller

In March 2020 as a campus shutdown loomed, the MIT Physics Department focused on its students. "We invited seniors outside to Killian, where staff and faculty saluted the graduates," recalls Academic Administrator Cathy Modica. "[Department Head] Peter Fisher gave a toast, [Undergraduate Coordinator] Emma Dunn created diploma-like certificates, and we laughed and cried. One senior approached me, instinctively reaching out for a hug, then remembered... but we hugged anyway. We didn't know if we would ever see each other again." Days later, students, staff, and faculty were told to pack up and leave campus.

Then-Associate Department Head Nergis Mavalvala first focused on logistics. “Initially I worried about the mechanics of online instruction. But we had tremendous expertise on those things, after years of delivering classes through MITx.” Faculty with digital teaching experience set up workshops for peers. Instructors created lab kits to mail to students’ homes.

With classes underway, Mavalvala then took a more holistic approach. “A bigger gap was how to support students’ well-being, as well as their learning,” she recalls. “We had no experience with the upheaval everyone faced, leaving campus with little notice, and regrouping online with differing personal circumstances and resources. A huge effort went into supporting struggling students. I kept pinging students to see if they were okay, to let them know, ‘I care about you, I need to know you’re okay.’”

The Physics Academic Programs Office located students who weren’t showing up for classes; connected students to academic and personal support; and with the help of Krishna Rajagopal, MIT Dean for Digital Learning and the William A.M. Burden Professor of Physics, guided those students needing technology support.

Professor of Physics and former Department Head Edmund Bertschinger created a mentorship program for students in 8.02 (Electricity and Magnetism), focusing on at-risk students. Associate Professor Kerstin Perez later expanded it to the fall 2020 sophomores. “Ed spun it up on very short notice,” says Deepto Chakrabarty, Professor of Physics and Associate Department Head. “It became a critical need during the pandemic to help students struggling with uncertainty. Kerstin laid a lot of the ground-work to train peer mentors, particularly targeting women and minority students.”

Students lost summer 2020 internships, research work and full-time jobs; the Department responded by soliciting over 75 remote UROP positions to fill the gaps. Professor of Physics Marin Soljačić offered

FIGURE 1:
Physics Department leadership and staff created an *en plein air* celebration to honor its graduating seniors in Killian Court—MIT’s traditional location for the annual spring Commencement. Credit: Deepto Chakrabarty

one-year research assistantships to three graduating seniors. “A simple action just at the right time can have such a large positive impact on people’s lives,” says Soljačić.

> “A simple action just at the right time can have such a large positive impact on people’s lives.”
>
> MARIN SOLJAČIĆ

With spring over, planning for fall 2020 began. The Department had to ensure an MIT-quality curriculum while demonstrating ongoing flexibility. “We were able to focus on the fall, we had time to think about it, to make MIT physics work educationally in an all-remote environment,” says Chakrabarty.

As the Department prepares to return, it may keep some of its on-the-fly solutions. “The 8.02 mentoring program and the summer UROP programs were quite successful, and I hope we will continue those,” said Mavalvala. “Asynchronous classes also had distinct advantages.”

Of course, not all the changes were keepers. “We should be honest with the challenges,” says Chakrabarty. “There are some things we simply cannot do effectively. Luckily, these things are very few. We were fortunate.”

As the new School of Science Dean, Mavalvala looks forward to ongoing debate about future online learning. “Engaging students in online learning is evolving,” she says. “I don’t think we’ve figured that out. And not having access to labs really detracted from the *manus* part of our *mens et manus* approach to education. But I’m optimistic that many of the lessons we learned will serve us well beyond this time of pandemic-driven remote learning.”

So, how did the Physics Department retool its classes for remote learning? Here were some of the approaches taken.

TEAL (Technology-enabled Active Learning)

Pre-lockdown, hundreds of first-years attended classes 8.01 (Classical Mechanics) and 8.02 (Electricity and Magnetism) at tables of nine in Building 26’s TEAL (technology-enabled active learning) classroom. These classes took a high-tech leap in 2001 (for 8.02), and 2003 (for 8.01) when John Belcher, Class of 1922 Professor of Physics, introduced the TEAL format. TEAL merged lectures, simulations, concept questions and group problems, and hands-on desktop experiments to create a collaborative learning experience. Students accessed online visualizations and simulations, lectures, problem sets, experiments and concept questions on MITx, much of which is on OpenCourseWare (OCW).

TEAL’s teaching team—eight section leaders plus lecturers, postdocs, a course manager, technical instructors and TAs—were primed to go fully remote. But it wasn’t easy.

“I remember talking with Peter [Dourmaskhin] every day to strategize, and working non-stop to get asynchronous content in place for the students,” says Physics lecturer Michelle Tomasik, who, along with senior lecturer Peter Dourmashkin, led the content review for spring 2020, fall 2020 and spring 2021 classes. Spring 2021 courses also were online. “I remember being pretty overwhelmed, but also pretty confident that we could provide a quality education to our students asynchronously and remotely.”

They were already using MITx, Dropbox, Piazza and Canvas, so quizzes were hosted on MITx. “This seemed like a perfect use of that content, mixed in with live Zoom support for students and hand grading of p-sets,” says Tomasik.

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> "I'm optimistic that many of the lessons we learned will serve us well beyond this time of pandemic-driven remote learning."
>
> NERGIS MAVALVALA

While many other classes slogged through long videos, TEAL's were streamlined. "We were able to present a lot of short videos with short problems immediately following that helped the students practice the concept they just watched," says Tomasik. "It was mimicking our TEAL classroom experience. We had deadlines for all those video/problem sequences to make sure people kept up to date. Starting in fall 2020, we made those problems due before the class, so that in-class problem discussion could be a review, going into greater depth for everyone. It's more of a flipped classroom than it was before."

FIGURE 2:
Like most, Physics lecturer Michelle Tomasik experienced Zoom overload during the extended lockdown. However, one unlooked for upside was the platform's usefulness in hiding bouts of morning sickness during meetings, via an easy activation of Zoom's stop-video feature. Tomasik with her second child, son Felix Cheng. Credit: Andrew Cheng

But the real gamechanger was adding the website platform *explain.mit.edu*, developed by Elton Lin '20, hosted by MIT and serving about 1,000 active users, including 8.01/8.02 students. Akin to Zoom on steroids, it's designed to consolidate the learning process with uploaded materials and archived Q&As. An online blackboard with audio and video offers collaborative workspaces for small groups; p-set lounges for quick meetings with the teaching team; and problem set collaborations with peers.

During a typical Friday problem-solving workshop, Dourmashkin starts with slides, and then sends students into breakout rooms per group assignments. He and TAs visited rooms to comment on p-sets, pulling up a digital whiteboard to illustrate a point. For whole-class announcements, he pulls everyone back. Dourmashkin says the hands-on teaching is key to generating excitement about physics.

"There are three important things that teachers generally do: You can deliver information; be a motivator; and be someone who can bring closure to any discussion," says Dourmashkin. "A lot of the work today is to motivate the students that they can successfully learn physics."

Because 8.02 students aren't sitting at tables with equipment, postdoc Alex Shvonski and technical instructor Joshua Wolfe led a team to assemble a kit for electricity and magnetism take-home design experiments, funded by a J-Wel grant.

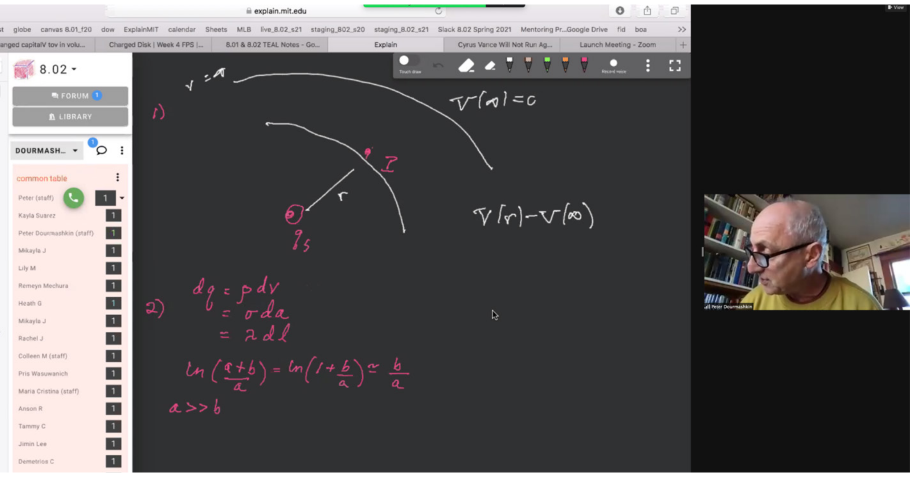


FIGURE 3 (LEFT):
Physics Senior Lecturer Peter Dourmashkin teaching 8.01 and 8.02 (TEAL) on website platform *explain.mit.edu*. Developed by Elton Lin '20, the platform hosts an online blackboard with audio and video, and offers collaborative workspaces for small groups, as well as p-set lounges for meetings with the teaching team and problem set collaborations with peers.

FIGURE 4 (BELOW):
Junior Lab's home lab kit includes (a) two pocket-sized "CosmicWatch" cosmic ray muon detectors, developed by student (now LNS postdoc) Spencer Axani, and (b) a Red Pitaya STEMLab board—a programmable signal generator and digitizer. Credit: Sean Robinson

Designed to build four basic experiments that test fundamental physics concepts, each kit includes wires, LEDs, magnets, 3D-printed LEGO pieces and a microprocessor used as a multimeter among other functions.

For fall and spring 2021, TEAL began grading attendance because participation in concept questions and group problems is essential. Says Tomasik, "There are several students who don't turn on their camera, but at least they do interact with each other because they are collectively working on a problem on an online whiteboard."

Junior Lab

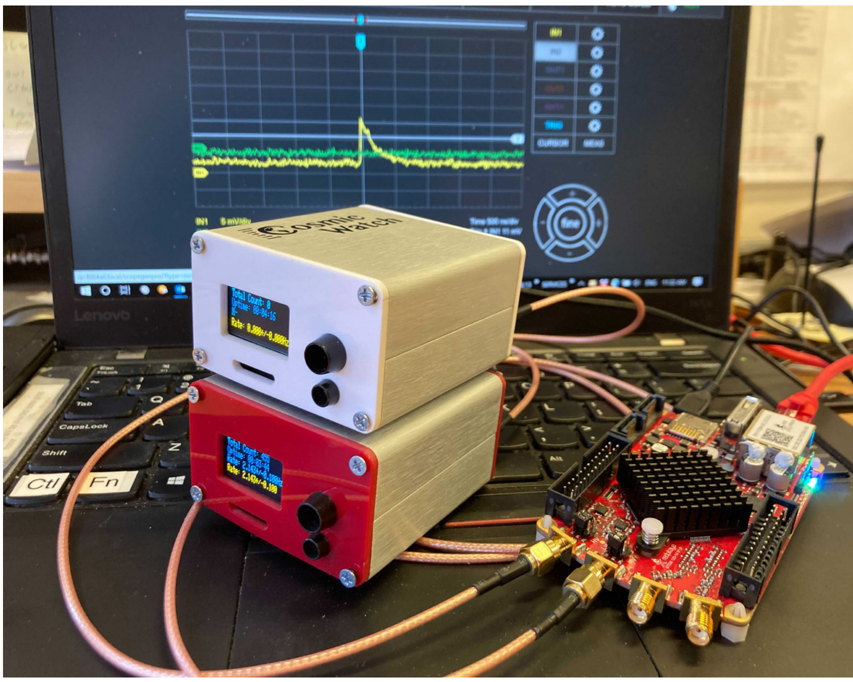
On March 13, 2020, Professor of Physics Gunther Roland was on his way to Taiwan, and Dr. Sean Robinson '99, PhD '05, Junior Lab Manager and Physics Lecturer, was at home rigging a workstation on a card table with equipment borrowed from the lab. Several students retreated to rural cabins; others reoriented themselves in various global time zones.

Roland and Robinson reinvented 8.13: Experimental Physics I ("Junior Lab") on the fly, and arranged for Cambridge-area staff to maintain lab equipment. Most 8.13 students were halfway through their first experiment before leaving campus, so they were told to just write up whatever data they had. Several planned projects were scrapped because they required hands-on access to the lab. The staff considered installing small robot arms to remotely rotate knobs, but quickly deemed it impractical. A few projects continued as planned with remote operation.

"There was lot of good will from the students, especially once they knew it was pass/fail grading," says Robinson.

But Junior Lab is not just about awesome experiments, it's about turning a physics student into a physicist. And they discovered that remote learning actually worked well for them.

"Collaboration is a really important part, and that can be practiced in a purer form



when practiced remotely," says Roland. "It was, of course, a very confusing time in terms of my personal life, but in terms of Junior Lab I saw it as an exciting challenge."

In July 2020, they learned few students would be on campus in the fall, so they brainstormed ideas for a shippable lab kit. It would include a Red Pitaya STEMLab board (a programmable signal generator and digitizer) and two pocket-sized "CosmicWatch" cosmic ray muon detectors, developed by graduate student Spencer Axani (now an MIT Laboratory for Nuclear Science postdoc). "These are very cute home-built things," says Robinson. But they are also professional-quality particle detectors, that needed to be assembled quickly. "We're building the resistors and the capacitors and the scintillators. We're drilling the holes. This is all in August [2020]. We needed to get these kits out before the September 15 exercises. Spencer is working full-time helping us build the kits. He's one of the heroes here."

Some kits were distributed to on-campus students in Killian Court, while MIT helped figure out how to ship others across the U.S. and to several countries with varying legal restrictions. It turns out you can't send nuclear particle detectors to certain parts of the world, so some student experiments needed customization. Shipping lags shifted lesson plans.

Another strategy was remote-controlled experiments. The lab's two-qubit NMR quantum computer could be run online. The Green Building's rooftop radio dish could

remotely make a radio map of the Milky Way (when either the VPN was working, or MIT Radio Society members made it past campus Covid-19 protocols to maintain the dish).

Other experiments could be performed in the actual lab, via “zombie” staffers. “At first, we started joking that we could be in the lab and turn things on, being controlled by the students remotely while wearing Go Pros, like robots,” says Robinson. But then they developed procedures to go into the lab for their students to make small changes, record responses and offer feedback. “On Slack, students could ask, ‘Can you turn the amplifier to 7?’”

Another longtime back burner item finally went live: pure computational projects, where pairs of students would analyze “big data” sets and computational models. Using publicly available data, instructors would help students replicate Nobel-level discoveries, from LIGO’s detection of two black holes colliding, to the Higgs boson observation at the LHC. “These are billion-dollar experiments, much more complex than what we can do in the lab,” says Roland.

For spring 2021, 8.13 remained a remote class as it was in fall 2020, but 8.14 would be taught as an in-person lab subject—reopening after 356 days without students. There is social distancing between lab partners and lab staff standing nearby, checking in via Slack. Most communication is from a distance, but when physical intervention is needed, “They back up from the bench, I go up to the bench,” Robinson says. “It’s a ballet.”

FIGURE 5 (LEFT):
Junior Lab students returning in March 2021, 356 days post-lockdown. Credit: Sean Robinson

By now, most of the lab experiments can be operated remotely, in addition to the take-home kits and data analysis projects. “It’s running pretty smoothly,” says Roland. “We have settled into a bit of a routine operation.”

With the switch to remote learning, Roland and Robinson saw improved communication, especially using Slack channels set up for different functions within the class, Zoom for group and class discussions and Dropbox Paper for online notebooks.

“You kind of forget you’re typing in a chatroom; it feels like a conversation,” says Robinson. “There are tone changes. The shy ones, when they are in the Slack channels to discuss tech issues, are writing like Dickens.”

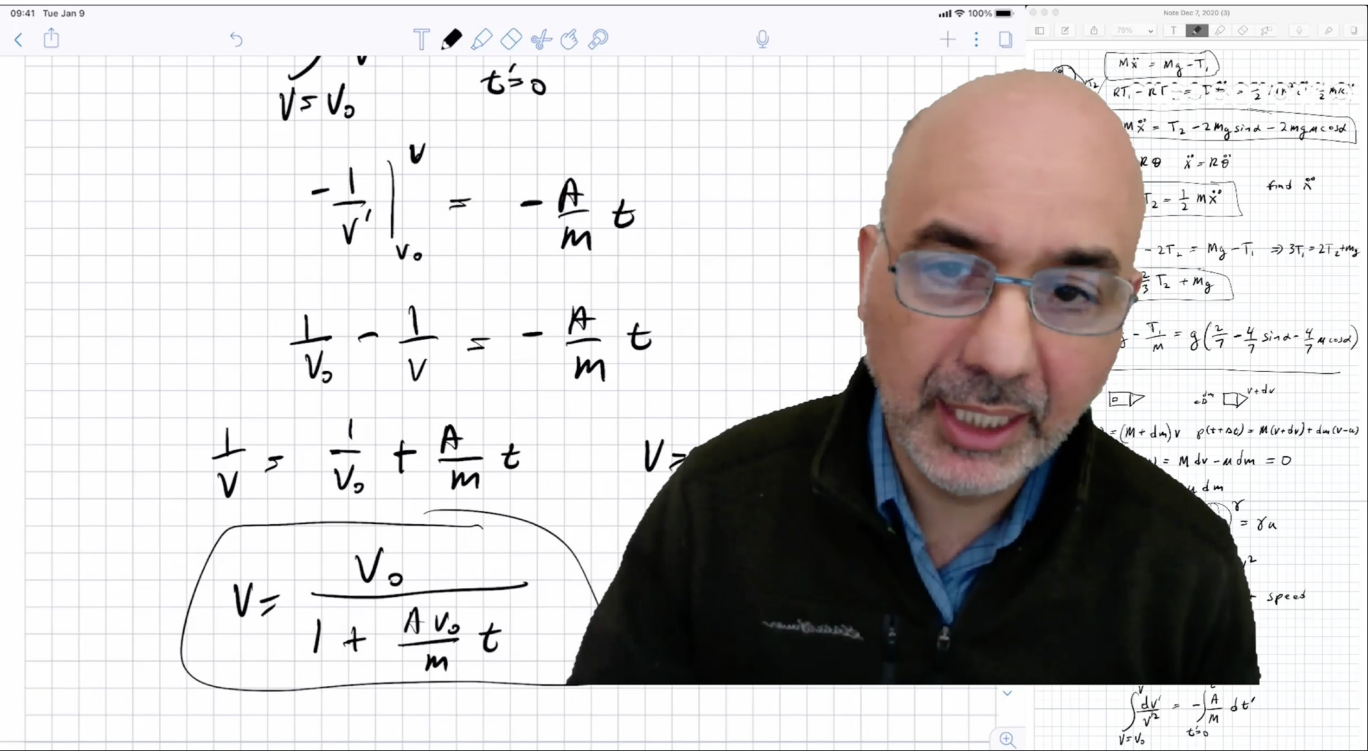
Adds Roland, “Before, there were lab sessions twice a week and the students were pretty busy doing their experiments. Now, the actual performance of the experiment is decoupled from the discussion time. I think it’s a very nice change, but it’s not so clear how we’re going to preserve that when we go back.”

Upper-Level Classes

When Professor of Physics Ray Ashoori, Division Head for Atomic, Biophysical and Condensed Matter Physics, and Professor of Physics Iain Stewart, Director of the Center for Theoretical Physics, were faced with shifting to online teaching, they tapped into their primary physics skills: innovation and curiosity.

Ashoori was lecturer for 8.022 (Electricity and Magnetism) in spring 2020. To quickly transition, he found YouTube videos to replace the in-class demonstrations, including some from the Department’s in-house lecture demo group, the TSG (Technical Services Group, led by Andrew Neely).

On Zoom, he was frustrated when he ran out of virtual chalkboard space. “In a classroom, I can write on six chalkboards, and the students can refer back to prior boards,” he says. Ashoori found that by pairing his



computer and iPad with free OBS Studio software, he could display several screens to show himself talking, while displaying his work and previous pages of notes. Zoom-in functions could then emphasize as needed. "This is kind of like having multiple chalkboards, and that way you don't end up having to scroll up and down all the time to show the students what you're doing," says Ashoori.

In another window he opens Notability, which combines handwriting, typing and photos. He syncs this via iCloud from his iPad so that he can project prior pages on the screen and uses the ChromaCam desktop webcam application so that his face and upper body float on the screen, and he can move his image around for emphasis. GitHub's OBS Virtual Camera plugin lets him stream his OBS output to a virtual camera source to view on Zoom. "I actually often keep the image of myself mirrored so that I can then use my left hand to do cross products without getting confused myself."

But Ashoori also likes Zoom for being able to talk and post problem sets at the same time, and seeing student names under their faces. "I like that I'm at my computer and can quickly pull things up in response to student questions," he says. "I can do things, like cut and paste, that I can't do on the blackboard." But much of the interaction still feels the same as in real-time, he says. "I feel that I get just as many questions in the Zoom classroom as I did in person."

Meanwhile, Iain Stewart was teaching 8.851 (Effective Field Theory) and its MOOC version on edX. "I was surprisingly well-prepared," says Stewart about his remote-teaching shift.

FIGURE 6 (ABOVE):
Professor Ray Ashoori in action within his 8.022 virtual classroom, using OBS Studio software to create an enhanced blackboard-style lecture.

FIGURE 7 (RIGHT):
Professor Iain Stewart's home office setup "after a flurry of March 2020 purchases," he says. "I use the built-in laptop camera for teaching and the camera at the top for all my other non-teaching meetings. The image on the central tablet is some of my 8.851 lecture notes."

During the early days of the lockdown he became the Department's remote-learning guru, including leading a Zoom-based faculty meeting to share tips on using Zoom, video editing, tablets, and MITx and edX. He later created a Piazza discussion forum, "8.Online-Edu," to share ideas.

> "We're not going back, we're going forward."
>
> IAIN STEWART

For 8.851's end-of-term video project, students presented during an all-day online session that accommodated different time zones. "We had students from the U.S., Iceland and Europe logging in over Zoom for eight hours, which was exhausting, but being able to do things like that opens up possibilities."

For Stewart's fall 2020 8.309 (Classical Mechanics III) course, he used Notability, moved his videos from a YouTube channel to the simpler Panopto, and dropped Stellar/Learning Modules in favor of Canvas for hosting the course and for exams. "Graders can mark up student solutions directly on a tablet and it's saved back in Canvas."

He has also been tinkering with Gather Town to encourage student interaction. "How do you simulate the experience of a student running into another student in the Physics common room, and then chatting about their homework?"

Stewart estimates that remote teaching takes 50 percent more of his time. "I can't just walk into a classroom with the knowledge in my head," he says. "Setting things up just takes longer."

For future classes, he'll keep Canvas, and he loves the option of teaching remotely if, say, he's at a conference. "We're not going back, we're going forward."

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