New trajectories in post-pandemic CS pedagogy

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ABSTRACT

The forced shift to remote instruction for the 2020-2021 academic school offered important lessons about how our computer science department delivers instruction to its undergraduate and graduate students. In particular, teaching remotely in the 2020-2021 year offered lessons about (1) how content is delivered to students; (2) how students are assessed for their learning; and (3) how students are supported in their learning. This case study outlines what instructors did in our CS department, what instructors and students had to say about these shifts, and concludes with key lessons and recommendations for CS instructors going forward. Our institution is a highly selective U.S. research university that operates on-campus instruction and has a history of online programs (historically aimed at continuing and professional learners), and offers lessons for CS departments at other universities with highly motivated students. However, we highlight specific teaching practices and course structures that can be used in any CS teaching context.

CCS CONCEPTS

• **Applied computing** → *Distance learning*; **Interactive learning environments**.

KEYWORDS

CS education, pedagogy, active learning, remote learning

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1 INTRODUCTION

Colleges and computer science departments worldwide creatively responded to the pressing need for remote instruction spurred by the global pandemic and its consequences. This case study examines the evolution of teaching practices and course models from spring 2020 to spring 2021. Importantly, it also captures key changes in student expectations that have followed. While many effects are easily observed at many institutions, the CS department represented in this case study had a different background than most. Housed in a highly selective research university with a large computer science teaching program at both undergraduate and graduate levels, this department also serves a remote student population that enrolls in the same on-campus classes as residential students.

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Previously active in the MOOC movement of the past decade, many instructors were accustomed to working with remote students, offering both alternative credentials, standard university credit, and degrees for a form of hybrid classes. Perhaps surprisingly, the instructors who approached pandemic instruction with the view that "we know how to do this" encountered some of the greatest difficulties. Rather, those who approached remote instruction of displaced students as a new design problem appear to have fared best, especially those who took the most care to monitor student conditions and adapt their teaching accordingly. Looking forward from a disruptive year, our primary question is: **What have we learned that can improve our future programs, for students on campus or afar?**

Goals. The aim of this paper is to document broad shifts in student expectations and instructional practices that have benefited CS students at one institution. We believe several pedagogical changes spurred by the pandemic will provide better learning opportunities for both continuing remote students and for on-campus students as they return. As we work to explore improved models of CS instruction across the scope of undergraduate and graduate courses, we see opportunities for thoughtful iterative improvement, including these sample areas:

(1) Recognizing the value of pre-recorded material and the impact of recording synchronous sessions
(2) Exploring improved approaches to active engagement in synchronous CS class time
(3) Appreciating multiple forms of formative and summative assessment, including revise-and-resubmit policies that support mastery-based learning.
(4) Leveraging the benefits of remote office hours and remote guest speakers
(5) Understanding the importance of frequent student feedback, responding to student needs with empathetic course policies, and providing multiple opportunities for help from course staff and peers

Overview. Our descriptive case study covers four academic terms of a quarter-based academic calendar. Redirecting our attention quickly to document rapid changes as best we could, we tabulated representative course designs, interviewed selected instructors, and compiled student opinions on various methods that were used between March 2020 and June 2021. The courses represented in this study normally see enrollment of 100-400 students in any term, including a fraction of students who would have been remote regardless of the pandemic. The largest periods of innovation were mad dash efforts in spring 2020, and the more deliberate redesign efforts during summer 2020 in preparation for fall 2020. Winter and spring 2021 brought incremental refinements as well as broader adoption of methods that proved fruitful across the department. Student reflection largely tracked instructor self-assessment, with some notable divergence around scheduling flexibility for students.

In documenting the year, we place our observations in three categories:

(1) **Instructor-directed sessions**, including synchronous and asynchronous presentations, small-group class meetings, and active-learning sessions in small or large class groups.
(2) **Student assessment** through homework projects and exams, including experimentation with options to drop one or more course requirements or show mastery of course material through revise-and-resubmit policies.
(3) **Student-initiated learning** such as office hours allowing students to seek assistance from course staff, and a new strategy of "homework parties" arranged to support student contact with their peers.

The remainder of this short paper is organized into three descriptive sections, one on each of the categories listed above, a discussion section that collects suggestions for future teaching, and a brief conclusion. The paper provides further information on how each of these three areas of course activities played out over the four academic terms of remote instruction, and then offers a set of takeaways. We conclude with recommendations for each of these three categories for instructors and course designers. While the collected suggestions are all consistent with pedagogical principles that were understood pre-pandemic, many have been normalized by a year of broader adoption.

As students and student expectations have been altered by a traumatic and life-changing year, instructors have largely been open-minded and resourceful in serving students successfully while confronting their own challenges. In this new context, we hope and believe that continuing adoption of a few thoughtful innovations will lead to more productive educational success in the coming era.

2 OBSERVATIONS AND DATA COLLECTION

2.1 Innovations in instructor-directed learning

Most classes before the pandemic used a traditional lecture format, meeting two to three times per week for 50-80 minutes each. Particularly among the lower division classes, several instructors are campus celebrities, known for their engaging presentations. A few instructors of upper-division classes are similarly regarded. Typically, graduate teaching assistants are assigned at a ratio of 25-30 students per assistant, with an additional head TA allocated for larger courses over a few hundred students. Teaching assistants can be involved in homework preparation, discussion or lab sections of courses, office hours providing direct student contact, and grading. Some courses are also partially supported by a professional course coordinator who oversees management aspects of the course.

For decades, many large-classroom lectures at this institution have been recorded on video and made available to enrolled residential and remote students. With lecture material available on demand, residential student attendance often drops to around 15% after the third week of class.

The main innovations explored in 2020-21 were:

- Recording expository presentations on pre-recorded video, made available on demand
- Designing synchronous class time to complement pre-recorded material, including
  - Fireside chats with high-level overviews, guest speakers, and Q&A
  - Problem sessions, often dividing the class in smaller groups or smaller sections
  - Real-time questions answered by course assistants over chat or online discussion platforms

Instructor and student response. Eighty-five percent of students responding to *ad hoc* survey said that it was "helpful" or "very helpful" to have lecture material pre-recorded and available at any time. We therefore expect strong student demand for video recording to continue into the future. While students strongly endorse the value of scheduling flexibility, we often saw the same low attendance in recorded synchronous online sessions as in our pre-pandemic in-person lectures. In our view, this suggests a need to deliberately design at least some portions of the course for active engagement.

Students had mixed reviews about synchronous sessions, as shown in Figure 1.

As noted above, there are some clear limitations with the student survey data since we don't know what practices each of the students were exposed to, as different classes used different approaches. Some enlightening comments from students included the value of having material in advance: *"I really enjoyed having some asynchronous material and then having synchronous lectures that delved deeper through real-world examples once the concepts were out of the way."* Other students spoke about the ability to ask question during class: *"TA and peer q and a during lectures was infinitely helpful."* Another student echoed the importance of active learning: *"The in-class problem solving activities in [course redacted] were great because we could anonymously message [name redacted] through zoom chat and then through what he said see what others are thinking/feeling."*

These remarks highlight the importance of using synchronous class meetings as a dynamic time for students to interact with their instructors to dive deeper into topics that they were already somewhat familiar with based on the pre-recorded lectures. The ability for students to ask more questions of their instructors (particularly anonymously) in real time, potentially using the TAs to facilitate the Q&A, was an important innovation that moves away from the previous model of largely one-way lectures.

At the same time, some instructors worked to make in-person-lecture-style sessions more popular and compelling for fully online students. A few remarked how they want to make a synchronous online lecture *"more akin to going to a music performance."* Indeed, some instructors who designed with new tools such as ***ohyay*** found that their attendance was higher in the latter weeks of the course than it normally was when they were teaching in-person, suggesting that there is *"still value to the synchronous lecture"* and in fact *"there are some aspects to better educating people in this [online] space."*

For some courses, TA-led small group sections provided a crucial opportunity for synchronous learning in the virtual setting. This builds on previous research that underscores the importance of near-peer mentors as approachable instructors. Student remarks about these discussion sections included: *"The only synchronous parts of class were section, which was helpful for reviewing content and/or getting elaborations on stuff I didn't understand."* Additionally,

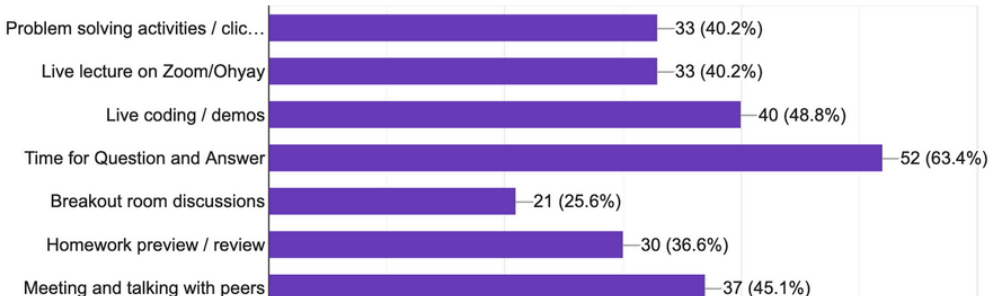

Figure 1: What aspects of synchronous class meetings did you appreciate? Check all that apply.

another student said: *"I think it is valuable to have sections meet synchronously. It was really valuable to interact with my peers and digest the material learned together....As people started to know in each other, the activities and interactions became more and more meaningful."*

2.2 Innovations in student assessment

Most classes before the pandemic used a combination of graded homework, quizzes, programming projects, midterm exams and cumulative high-stakes final exams. Grading has traditionally been competitive, with students feeling considerable pressure and anxiety even though grade curves often lead to a substantial number of high overall course grades. Meanwhile, remote students do the same class work as residential students enrolled in the same class. University policy in spring 2020 required that all classes be taken pass/fail, and the 2020-2021 school year prohibited high stakes final exams and eliminated the final exam week, although it should be recognized that some instructors replicated their traditional exam structures despite official policies.

The primary innovations observed during the four quarters of 2020-21 were:

- Multiple lower stakes exams or assignments in lieu of one final exam
- Revise and resubmit, allowing students to revise work they turned in and receive a higher grade (also known as mastery-based learning)
- Pass/Fail grading policies
- Partner / group assignments or exams
- Concept checks, used regularly or weekly to track student academic progress and personal wellbeing

Instructor and student response.

Rethinking final exams. The remote learning environment prompted instructors to recognize the unequal access to stable learning environments and resources while students were under lockdown in their respective homes. For that reason, instructors who traditionally relied on final exams pivoted towards lower-stakes exams or a greater emphasis on assignments and projects.

One instructor explained that he would not use any exams during the pandemic so as not to amplify disadvantages; he updated the grading policy to focus on assignment grades instead. He also provided optional exams in case students wanted to self-assess their knowledge. As he said: *"Right now... there are students who are not outfitted to be able to take exams ... Assuming that the people who are at a disadvantage and taking exams right now are probably not the people who would normally get top 5% on an exam, that they're bringing a lot of their shortcomings, even to campus,...to actually amplify that disadvantage is actually I think just not right."*

70% of students surveyed considered it beneficial or very beneficial to have multiple smaller exams in lieu of one final exam, and 69% of students surveyed found partner / group assignments beneficial or very beneficial. Students voiced appreciation for the changes above, which reduced stress: *"It was helpful to not have exams in [course redacted] since I often struggle with exams but definitely understood the material based on the self-assessments and the assignments, so it just removed a lot of unnecessary stress."* Some instructors who continued to give exams chose to accommodate more students by giving a 24-hour window to complete exams or by giving shorter exams. By giving shorter exams, some instructors also hoped to dissuade students from cheating, which remained a concern in the virtual learning environment. Two CS1 instructors reflected: *"To mitigate [cheating] we only gave them 25 minutes so it's ...not enough time for you to cheat."*

Revise and resubmit. For other instructors, the remote learning environment proved to be an opportunity to pilot mastery-based learning, which includes policies that allow students to revise and resubmit until they felt that they had achieved mastery in what they learned. As one instructor explained: *"I've always wanted to experiment with some form of mastery learning, and this was my chance! We have 3 take-home exams, and after each take-home exam is graded, students whose work was unsatisfactory have an opportunity (with extensive feedback and staff support, though not the actual solutions) to revise and resubmit their work a week later. Students whose work is still unsatisfactory can revise & resubmit again, with more staff support."*

Students responded favorably to these policies: 75% of students who were in a course that offered the option to revise and resubmit work considered it beneficial or very beneficial to have the option to do so. The following comments from students spoke to the advantages of a mastery-based approach using a revise and resubmit policy: *"[Instructor redacted]'s revise and resubmit policy in [course redacted] was fantastic. It meant I could engage with topics until I reached mastery, rather than just settling for 'good enough.'"* The

sentiment was echoed from other students: *"My learning experience feels so much more whole now that I've worked out the correct answer to every single midterm problem; I know this method of revision might be controversial because it doesn't provide a memorization-based meritocracy grade distribution, but I feel like the CS program here has explained it's goal to be to make all of us excellent programmers through hard work - which I think rewards revision, getting us students back on their feet after what might've been a demoralizing fall from grace.*

Pass / Fail Grading Policies. The ability to take courses for a Pass/Fail grade instead of a letter grade changed students' attitudes towards assessment. Teaching team members of the CS1 courses reflected on why Pass-Fail might be a helpful policy to level the playing field for introductory CS courses: *"I think it's not completely fair for intro CS classes to not be pass fail because there are people who come in with different backgrounds ... there are people who start [CS1] who had never coded before in their life and I have students who ... had coded since they were in middle school."*

Weekly concept checks. A number of courses created short quizzes each week for students to assess their understanding. 56% of students surveyed who had weekly "concept checks" in their courses considered it beneficial or very beneficial to do them. The following comment reflects student appreciation for instructors use of "concept checks" to accompany the asynchronous lectures in a flipped classroom environment: *"Weekly concept checks in [course redacted] also helped me stay on track with the asynchronous lecture videos, and I thought that was a great idea because I never got behind on lecture which I often do."*

2.3 Innovations in student-initiated learning

Prior to the pandemic, office hours for larger lower-division classes were traditionally held in a designated location on campus at multiple times throughout the week. The space, referred to here as "the basement", was often full of student activity, with spontaneous group formation, peer help and small group instruction with skilled TAs. Many students also had peers they could rely on to work with through class connections or other relationships they had built (for example being on the same sports team or in the same student organization).

With the shift to remote instruction, these student-initiated learning options were arguably the hardest area to replace. Many of the ways that residential life supports student learning were taken for granted before the pandemic. Because the organizational structure of student peer collaboration was largely invisible to instructors, many instructors began the pandemic with little concrete understanding of how to replace residential peer learning. Because there was no single solution for this complex problem, iterative experiments with a range of platforms and techniques continued through the 2020-21 academic year, including:

- Discussion forums, allowing students to ask questions and other students or course staff to answer online.
- One-on-one office hours with course staff, as either drop-in, or appointments (15 minutes), one-on-one help sessions for homework or non-homework help, also called "helper hours"
- Working office hours, allowing students to join online rooms to work and communicate with other students, generally without course staff.
- "Homework Parties," in which students can gather remotely and study or work together, with course staff present at each session to provide help.

Unlike in the teacher initiated activities and the assessments, experiments in student-initiated learning struggled to replicate many of the in-person benefits of office hours and informal campus study options. However, a number of these formats were highly beneficial to the students that chose to take advantage of them. This suggests that hybrid structures supporting student collaboration might lead to interesting innovations in the future.

Instructor and student response. Although there were definitely challenges with the online delivery of activities associated with student initiated learning, it is evident that students want to keep the option of online supports in the future: *"Online OH [office hours] are so much more accessible and I actually feel like I got a lot more help this year than in previous years. [The basement] is chaotic and CAs are often running around like crazy and attention is always divided. [Course redacted] group office hours functioned really well online and my other classes ... had individual online OH that worked super, super well."* One graduate student compared the online option to the in-person experience: *"Virtual OH with queues are, in my opinion, the best thing about remote courses and I hope continue when things go back to normal... the virtual queues on Nooks and Zoom made the process way more equitable ... And probably most crucially, if OH were crowded and there was a long queue, you could just stay on the queue and comfortably do other work from your own home or location as you waited to get helped. That itself was a SIGNIFICANT boost over my experience in undergrad and I don't think can be replicated well in a crowded, loud, physical OH space."*

A number of students explicitly called out the benefit of using the ***Nooks*** platform as a preferable alternative for office hours to ***Zoom***. Finally, other students expressed appreciation for the active role that instructors took on in online discussion spaces: *"[Instructor redacted] had a Slack workspace and he and the TA's were super active on it. I felt like I could receive and offer help to classmates, and I really felt like a part of a community."*

3 INSIGHTS AND RECOMMENDATIONS

3.1 Instructor-directed sessions insights

The case study from our institution suggests four key takeaways from the experiments in instructor-directed sessions tried over the past year. These are that:

(1) Student appreciate when instructors make asynchronous video lessons available prior to class meetings because it gives students an opportunity to get better acquainted with the material and maximizes the learning in synchronous sessions.
(2) Synchronous class time is most beneficial to students when designed around "active learning" activities such as live problem practice, question and answers with the instructor/teaching team, fireside chats with guest speakers, and extending course material to apply it to real world scenarios.

(3) Using technology to enable more opportunities for students to interact with the teaching team and with peers during synchronous class time makes learning more visible and creates more opportunities for important discussions
(4) Instructors that collect frequent student feedback using surveys and check ins have a better pulse on how their students are doing in the class and in their personal lives, and this empathy translates to a better learning experience for students

Two of these changes speak to shifting trends over the past decade of CS education research that feel particularly useful to elaborate upon.

Make asynchronous videos available. One clear trend is that students strongly value the scheduling flexibility of asynchronous video presentations. During the pandemic, this was particularly important for students in varying time zones. However, students participating in athletics or other extracurriculars cite the same advantages for residential course offerings. In addition, the ability to watch short lecture videos prior to synchronous course meetings increases the value of the time spent as a group. What was once seen as a "nice to have" addition to a course appears to becoming an expectation for all CS courses.

Recommendation: Make (short) pre-recorded videos available so that students can cover the material at their own pace and can be better prepared to utilize synchronous class activities to maximize their learning. This can also reduce the number of synchronous class meetings per week.

New models of active learning in CS. Active learning teaching practices in Physics [1] and other STEM disciplines have been around for quite a long time, and have even found their way into CS courses [2]. While many instructors were hesitant to change their practices and move away from traditional lectures during synchronous class time prior to the pandemic, the shift to remote instruction caused many to rethink how to best use synchronous meetings. The experiments at our institution did not reveal one "best way" to engage students during synchronous class meetings. However, the four quarters of instruction did reveal that students preferred classes in which they were (1) actively solving practice problems in class, (2) able to ask questions of the instructor and the TAs, (3) getting targeted practice on specific topics with the instructor and TAs, (4) able to learn about real world applications of relevant course topics, including from guest speakers who are professionals in the field.

These findings suggest that "active learning" might need to be more explicitly defined in CS to encompass a broad range of activities in which students are engaged with the instructor, the TAs, their classmates and/or guest speakers during synchronous meetings. Making the course responsive to student needs and questions, while creating opportunities to take advantage of the precious human resources and opportunities for social interaction appears to greatly benefit learning [3].

Recommendation: Instructors should structure synchronous class time to engage students in activities, dialogue and practice problems that make learning more social and provide opportunities for human interaction. Instructors should survey their students and collect frequent feedback so that they can continue to experiment and iterate with new formats for "active learning" methodologies that are best suited to CS instruction in their courses.

3.2 Assessment insights

Assessment is a complicated topic that has long been debated in education circles, including in CS education. The choice by many institutions to require Pass/Fail grading in spring 2020 in response to the pandemic forced instructors and students to approach grades and assessment differently than they had in the past. Some students found it liberating, while others were stressed about not knowing how to get an A in these new class formats. The experiments in formative and summative assessments highlighted a few keys points around assessing student understanding in CS classes:

(1) There are multiple ways to assess student learning, both through formative and summative assessment. High stakes exams are not the only way to assess student learning, and more frequent exams and concept checks might help students to assess how they are doing in a course. Projects, group assignments and homeworks can all help to illuminate student understanding of the material.
(2) Revise and resubmit policies that support mastery of course material reduce students stress and provide powerful opportunities for student learning and success. Support of these policies suggests that a forced grading curve is not necessary, particularly in introductory courses.
(3) Online exams are susceptible to cheating and misuse
(4) Some students appreciate grades and need graded transcripts to apply for jobs and future degrees, while others are more focused on learning.

Most notably, the shift in assessment formats and related course policies revealed key lessons around how to most effectively use assessments for student learning, as well as the possibilities for mastery-based models of learning where students can keep working on a topic until they have demonstrated understandign of the topic.

Formative and summative assessments can take many forms. Important innovations from the past experiments at our institution included the use of frequent "concept checks" for students to self-assess their understanding of the material as they moved through the course, rather than having to wait for a higher stakes midterm exam to find out how well they understood the content. Similarly, more frequent lower takes summative exams seemed to reduce the stress on students, and allow for faster learning cycles. Looking ahead, more frequent assessment can also lead to different formats for gauging student understanding, such as projects, group assignments and students taking on more peer teaching responsibilities. (Education research speaks to the importance of student agency in showing mastery, and the past year's experiments appear to support that and shed light on new ways of assessing student understanding in CS).

Recommendation: Use frequent assessment to reduce student stress and scaffold learning effectively.

Mastery-Based Learning policies such as "revise and resubmit" support student agency & learning. Students who had the opportunity to "revise and resubmit" homework and assessments found that they were better able to learn the content because they felt supported in continuing to learn the material until they

proved they had mastered it. Similar approaches, often termed mastery-based or competency-based learning in education research [4], has been shown to improve student outcomes by shifting the focus away from exams to learning. The incredible response by students and instructors alike to these policies suggest that both groups see tremendous benefits in this approach, with opportunities to support learners without putting too much of a burden on instructors.

Recommendation: Consider adopting policies that support mastery learning methods.

3.3 Student-initiated learning insights

Shifting office hours and related essential yet often overlooked learning structures online was a major challenge at our institution. The ability to recreate the types of TA and peer help systems that informally and spontaneously arise in residential institutions was not possible in online settings. However, new systems did emerge that suggest that there are more ways to reach students, especially those struggling in courses. Key insights included:

(1) Both in person and online office hours benefit students, and it is important to have both options going forward as certain formats benefits certain types of students.
(2) Creating opportunities for students to collaboratively work together and help each other should be more deliberately designed for going forward because leaving it to chance advantages certain students (e.g. students with more friends in the major, part of a group that can help them, people willing to ask questions in class, people unafraid to go to crowded office hours, etc.)
(3) Students get help from TAs as well as peer students and there should be formal opportunities for these different types of help structures

Looking to the 2021-2022 school year, it is evident that students at our institution are excited to be back on campus in proximity to their peers and with access to residential services, especially academic ones. However, the role of online help structures should not be overlooked as a key resource for many students.

Recognize that students have differential prior experiences and meet students where they are The strong desire to both return to in-person office hours and to keep online office hours, as well as other new structures such as "homework parties" suggests that different students learn in different ways, and that these different supports can benefit students. For some that don't feel comfortable in hectic environments or in-person interactions, online office hours will continue to be their preferred method for seeking help (some TAs might prefer this as well). For students that like group environments, an in-person setting might be preferred. For students without strong social connections in their classes, facilitated "homework parties" can provide invaluable access to peer learners. The key takeaway for instructors and course designers is to find out what different students need and be responsive so that everyone has an equal shot at success in their course regardless of their prior background.

Recommendation: Meet students where they are by creating multiple formats for students to get support that privilege different student backgrounds and different learning styles, including online and in-person formats.

4 CONCLUSION

A descriptive case study of four academic quarters from spring 2020 to summer 2021 revealed energetic innovation and iterative experimentation. Student comments and responses strongly suggest that student expectations and demands will be changed dramatically by this period. While instructor innovation has been rapid, without time or adequate data collection to draw highly quantitative conclusions, several trends are more than apparent. Given instructor investment in the work they have done over the past year, and the receptiveness of students to many of these innovations, the most promising steps forward will draw productively on the 2020-21 experience. Specific suggestions are given in section 3.

Trends in instructor-led sessions. One clear trend is that students came to value the scheduling flexibility of asynchronous video presentations. Based on current and prior experience, it is virtually certain that pre-recorded video and class session recordings will continue to be valuable. However, with the low student attendance that occurs when synchronous online sessions are recorded and accessible on demand, there is a need to thoughtfully design a portion of course activities to foster productive student engagement.

Trends in student assessment. Instructor views of assessment changed over the course of the year. Many provided more flexible deadlines to accommodate students in challenging circumstances. More substantively, a number of instructors replaced their single high-stakes final exam with alternatives and explored mastery-based learning, commonly presented through revise-and-resubmit policies. A departure from the previous culture of grade competition, experiments in mastery learning may foster new instructor values with lasting impact.

Trends in student-initiated learning. Many of the ways that residential life supports student learning were taken for granted before the pandemic, but became shockingly apparent as soon as we were confronted with their loss. Because the organizational structure of student peer collaboration was largely invisible to instructors, instructors began the pandemic with little concrete understanding of how to replace residential peer learning. Because there was no single solution for this complex problem, iterative experiments with a range of platforms and techniques continued through the 2020-21 academic year.

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