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From crisis to opportunity: practices and technologies for a more effective post-COVID classroom

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Abstract
In our post-pandemic world, where the majority of higher education institutions have transitioned back to in-person classes, this paper argues that we must not return to pre-COVID teaching practices. Instead, we have the obligation and opportunity to create an educational experience and environment that better facilitates learning and instruction. This paper presents post-COVID best practices for employing technology in higher education based on an original survey and follow-up interviews of seventeen computing instructors at our institution. After a literature review, we describe four general categories of practices that enhance the post-COVID classroom: online student activities, digital instructor notes, remote classroom participation and collaboration, and a paperless classroom. For each of these categories, we provide vignettes to illustrate scope and intent. We also offer recommendations for addressing digital dishonesty, required infrastructure, institutional support, and being prepared to seamlessly return to a blended or fully remote environment in the event of another crisis. Finally, we identify additional emerging technological challenges and opportunities that require further effort. Overall, this paper emphasizes the need for a shift towards improved practices in the classroom rather than just a return to pre-pandemic norms. We believe implementing these recommendations will result in a more flexible, accessible, and robust post-COVID educational experience.

Keywords COVID-19 · Digital teaching practices · Computer aided instruction · Teaching · Educational technology · Remote office hours · Paperless classroom · Digital lecture notes · Online student activities

Jeremie Regnier, Ethan Shafer, Edward Sobiesk, Nicholas Stave, and Malcolm Haynes contributed equally to this work.

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1 Introduction

The COVID-19 pandemic of 2020 presented many challenges for higher education institutions, resulting in the rapid implementation of emergency remote teaching and the suspension of in-person instruction. Despite these obstacles, educators across the board adapted, innovated, and made significant sacrifices to ensure that course content was delivered in a way that minimized impact on the educational experience. This was initially accomplished through various tools such as webcams, microphones, videos, and screen sharing. Academic literature has documented many further innovative mitigation practices produced during the crisis, as is highlighted in the background section of this paper.

However, now that higher education institutions have returned to in-person classes in the currently post-pandemic world, this paper contends that it is not sufficient to simply revert to pre-COVID teaching practices. Instead, we have a unique opportunity and responsibility to move forward and create an educational experience and environment that better facilitates learning and high-quality instruction while maintaining the ability to transition smoothly back to remote delivery modes, if needed. This paper is a call for and contribution to such an effort.

Inspired by relevant literature and drawing on a survey and interviews of our department's computing faculty, we present COVID-related teaching practices that we recommend continuing to employ. We describe in detail four general practices that enhance the post-COVID classroom: online student activities, digital instructor notes, remote classroom participation and collaboration, and a paperless classroom. For each practice, we relate vignettes to illustrate creative and effective ways it can be implemented. Although our examples are drawn from computing curricula, the suggested practices we outline may be applicable to any field of study. We additionally offer recommendations addressing digital dishonesty, required infrastructure, institutional support, and the need to maintain the ability to resume remote teaching. Finally, we describe emerging technological challenges and opportunities that demand further research.

Some may find our discussion and recommendations self-evident, however, we have repeatedly observed an inclination towards reverting to pre-pandemic teaching methods and techniques as the amount of time since the COVID lockdown increases. Therefore, we believe now is the moment to re-energize the effort to bounce forward in higher education by incorporating the insights, tools, and practices derived from the past three years of effort. Our paper consolidates and describes many of these established best practices, aiming to create a post-COVID educational environment that is better, stronger, more flexible, and more accessible than it was pre-crisis. In addition, in the event of another crisis, our instructors, students, and infrastructures must be ready to return to blended or fully remote teaching.

2 Background

The most comprehensive related work is the 25-page report "Teaching through a Global Pandemic: Educational Landscapes Before, During and After COVID-19," produced by a 12-person Working Group and published in association with the 26th

ACM Conference on Innovation and Technology in Computer Science Education (ITiCSE 2021) (Siegel et al., 2022). This report is comprised of three significant parts.

The first part of the report by the ITiCSE 2021 working group (Siegel et al., 2022) examines 80 pertinent publications gathered from a range of sources that included SIGCSE, ITiCSE, ICER, UKICER, Koli Calling, FIE, EDUCON, and various journals. These publications were analyzed and categorized into five areas: (1) pedagogy and practice; (2) value changes; (3) inclusion and diversity; (4) community, belonging, and well-being; and (5) academic integrity. Our work builds upon and expands several of these categories – in particular, their pedagogy and practice section exploring various changes and innovations in course structure/design, including the use of tools and technologies for blended learning. However, a key difference between our work and the ITiCSE 2021 working group report is that most of the papers they analyzed focused on how to adapt to the COVID environment, while our focus is on the post-crisis period.

The second part of the ITiCSE 2021 working group report (Siegel et al., 2022) details the results of a survey of 180 computer science faculty members from multiple countries that focused on their transition to remote learning during the COVID pandemic. The survey explored pedagogy and practices, technology use, and assessment practices and their relationship with academic integrity. This section of the report provides valuable insights and inspiration, showcasing numerous real-world examples of how the field adapted and innovated in response to the shift to remote learning and blended environments. Our paper builds on this information by explicitly addressing how COVID practices can be integrated into in-person classrooms.

The third part of the ITiCSE 2021 working group report (Siegel et al., 2022) contains recommendations for future action. These recommendations include guidelines for utilizing technology in teaching, ways to enhance support for faculty and student well-being, and a call for further research in the areas discussed. Our work is a response to this call for future research in computing education.

Although the ITiCSE 2021 working group report was a valuable contribution to the field, a shortcoming is that it should have surveyed and included a significant number of relevant COVID-related publications from the 2020 and 2021 ACM Conference on Information Technology Education (SIGITE). Our literature review uncovered at least nine additional SIGITE papers (Bai et al., 2020; Bringula et al., 2021; Chhetri, 2020; Diederich et al., 2020; Dupuis et al., 2021; Dupuis & Renaud, 2020; Glantz & Gamrat, 2020; Shichtman, 2020; Williams et al., 2021), as well as several posters and panels, that could have been included in the ITiCSE 2021 working group's effort.

In addition to the papers not included in the ITiCSE 2021 report, further related works have been published after the completion of the ITiCSE report. Many high-quality papers continue to study and report on various elements of the COVID educational experience, including best practices and tools to mitigate remote/blended teaching along with what impacts the crisis had on both teaching and students. The most relevant of these recent works include (Corral & Fronza, 2022; Du et al., 2022; Fokum, 2022; Koniarik et al., 2022; Lee et al., 2021; Marciniak et al., 2022; Sharmin & Zhang, 2022; Zheng & Zheng, 2022).

Although we found all of the above efforts valuable, the papers most connected to our current work dealt with course structure/design, integration of tools and technologies to support a remote classroom, and academic integrity in a remote environment. Our present paper extends our work described in Stave et al. (2022) by further revising our suggested practices and increasing the vignettes that elaborate on them, suggesting potential tools for implementation of the practices, and discussing digital dishonesty, required infrastructure, institutional support, preparation for return to remote teaching, and emerging technological challenges and opportunities that require further research.

3 Post-COVID technology use survey

During the peak of the COVID pandemic, universities discontinued in-person classes and required instructors to teach remotely. To support remote learning, educators utilized various technologies. They frequently conducted classes through video conferencing platforms like Zoom or uploaded lesson videos to online learning management systems like Blackboard and Canvas.

While advanced educational technologies existed prior to the COVID crisis, many were not fully embraced. For example, smart boards were available in many educational institutions but were not widely adopted by teachers (Korkmaz & Cakil, 2013). The shift to fully remote teaching required instructors to become familiar or re-familiarize themselves with these platforms and technologies.

As in-person education resumed, we wanted to determine if any educational technologies initially used as a result of COVID were still in use in undergraduate computing education. In Fig. 1, we present the results of a survey of computing faculty at our institution to determine if they were continuing to use the technologies and practices they implemented in their classes during COVID.

We conducted the survey in April of 2022 using Microsoft Forms with multiple-choice and open-response questions. Seventeen instructors from the electrical engineering and computer science department at our institution participated in our survey. Out of these, 76% (13 out of 17) state that they are still using some of the technologies and practices in their classrooms that they adopted mainly due to the COVID crisis.

The survey also asked instructors to elaborate on how they are still utilizing COVID-related technologies in their classes. We collected several descriptive accounts from the survey and followed up with interviews. We present the results as vignettes throughout the paper. Our analysis of the survey responses and instructor interviews revealed four recurring patterns in the continued use of COVID-adapted teaching practices:

1 online student activities.
2 digital instructor notes.
3 remote classroom participation and collaboration.
4 a paperless classroom.

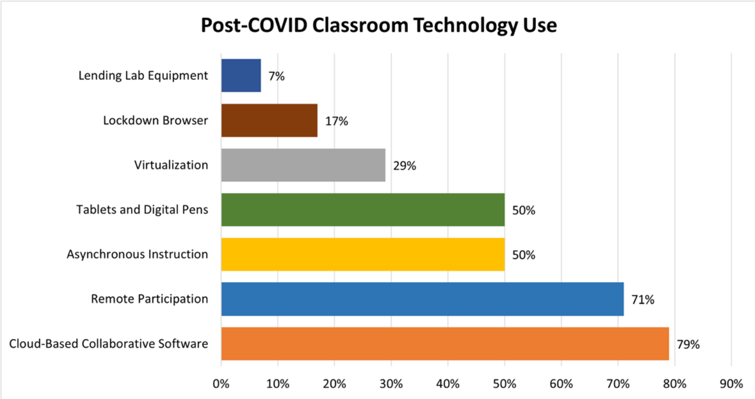

Fig. 1 Results of a survey of our computing faculty of which technologies and techniques are still being used for in-person classes that were initially used as a result of COVID (n = 17)

While this paper focuses on computing classes and faculty, the practices discussed below can be applied to a variety of courses and disciplines.

4 Online student activities

When students do problems on chalkboards to show understanding, it is sometimes referred to as "board work." This practice is most prevalent in math and science classes and allows the teacher to assess student understanding while providing an opportunity for peer learning and feedback. Board work can also help students develop their communication and problem-solving skills as they explain their thought processes and reasoning to the class. This style of learning is not often used in higher education, which typically follows a lecture/homework structure. However, the adoption of the "flipped" classroom in higher education is gaining traction (O'Flaherty & Phillips, 2015). Flipped classrooms better lend themselves to in-class activities, which have been shown to be an effective learning method (Wilson, 2013). In computing classrooms, in-class activities have often taken place in a computer lab where students perform various tasks such as programming or system administration using computer systems located in the lab. During the lab, teachers assist students as the students encounter various problems. However, when institutions were shut down during COVID, the computer lab model had to be revised because restrictions prohibited students from coming to the labs. As a result, many teachers started or expanded the use of online and cloud-based labs. Since COVID ended, some instructors in the computing department at our institution did not return to the traditional computer lab model but continued to use online and cloud-based in-class activities during even their in-person classes. They found that these technologies can enhance in-person learning.

4.1 Vignette—cloud-based integrated development environment in an introductory computer programming course

An introductory programming course at our institution extensively uses in-class programming activities to help students learn fundamental concepts. Prior to COVID, students in the class wrote and executed programs on their personal computers. To assist a struggling student during class, a teacher would walk to the student's seat, look at the student's screen to see the code the student was working on and offer verbal feedback.

With the advent of COVID, teachers had to transition to a different mode of interaction since classes were not conducted in person. The solution was to move to a cloud-based, collaborative, integrated development environment (IDE). The cloud IDE enabled teachers to remotely view, comment on, and edit students' programs in real-time as students were coding. There are many cloud-based IDEs to choose from, such as Codio, Coding Rooms, Code Sandbox, and Replit, amongst others. Figure 2 displays an example screenshot of side-by-side teacher and student views in Replit. Although first used in response to COVID, the course continued to use the cloud-based IDE even after the return to in-person classes. Instructors found they could provide verbal feedback on a student's coding efforts, as had been always done during in-person classes, but they could also easily provide digital feedback. Digital feedback has some advantages over verbal feedback in that it is enduring, and the student can refer to it throughout the coding activity, even after the teacher moves on to work with another student. Further, using a cloud-based IDE allows instructors to provide a tailored combination of verbal and digital feedback as appropriate for each student.

Another benefit of a cloud-based IDE for in-person classes is peer learning. While there are advantages to peer learning (Topping, 2005), in programming classes, peer

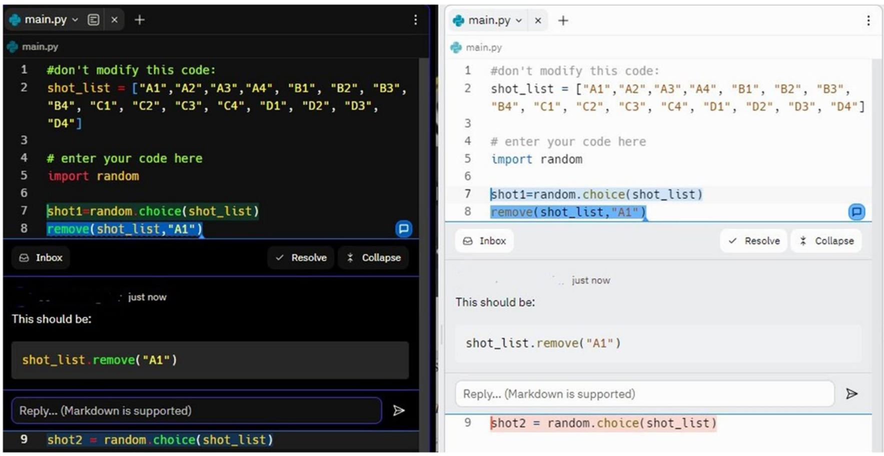

Fig. 2 With Replit, instructors can see and comment in real-time on their students' code. The left-hand side shows the instructor's view of a student's screen and the right side shows the student's view. The two views update in real-time as either student or teacher edit or make comments

learning has typically been difficult to execute. For example, a teacher may want a student to share their code and discuss their solution with the rest of the class. When the code only exists on the student's computer, it is often difficult and time-consuming to adjust a classroom projection system to show the student's code. However, when the code resides in the cloud, the teacher can project it to the class in seconds without changing the classroom setup. Students can then explain and discuss their code with the class without needing to leave their desks or write voluminous programming statements on a board. Likewise, students can collaborate during class, with each student working on a different part of a program. They can share, review, and discuss each other's code. These peer learning practices, facilitated by a shared cloud-based IDE, allow students to learn from each other's successes and errors.

4.2 Vignette—online virtualization in a distributed applications course

The COVID pandemic brought significant changes to the teaching methods of a distributed applications design course taught by one of the surveyed instructors. The course features a project in which students develop and deploy a web application with both a front-end and a back-end database. Traditionally, students would work on this project as in-class exercises, which provided opportunities for the instructor to observe their work, answer questions, and provide guidance. However, COVID restrictions made it impossible to conduct these in-person exercises, which posed a challenge for effectively delivering the course.

The instructor adapted to the remote teaching limitations by utilizing virtualization. The students developed their projects on virtual machines (VM) hosted by the department rather than on their laptops. The management features of the VM infrastructure provided the instructor with the ability to monitor the students' VM desktops in real-time, leading to enhanced efficiency and improved instructor feedback. Additionally, the instructor was able to be physically remote while observing the students' screens and addressing any issues. Anyone who has performed troubleshooting over the phone is familiar with the difficulties inherent in not being able to see what is occurring. The ability to view the students' screens via virtualization greatly alleviates these problems.

An additional benefit of virtualization is that the instructor can simultaneously monitor multiple VM feeds while giving a lecture or discussing the in-class exercises. While this may seem minor, it presents an excellent opportunity to close the feedback loop while instructing. Typically instructors rely on student interaction (e.g., asking or answering questions) to assess whether they understand the material. By monitoring students' VMs and providing live feedback, instructors can create a more positive learning experience for the students. If the instructor observes multiple students struggling with the material or not following along properly, the instructor can slow down and clarify the difficult topics.

Virtualization also benefits course administration. VMs help get around privacy concerns that students may have when screen-sharing from a personal laptop. Since the VM is hosted separately from the student's laptop, there is less risk of the instructor observing something personal or private. Additionally, VM snapshots can be taken while building a project or assignment. Without these snapshots, if students have a configuration error or do not correctly complete a previous assignment, they must first fix the issues before completing the current assignment. Using VM snapshots, however, the instructor can ensure that at each step of the assignment, all students will start from a known and correct baseline.

Virtualization has its drawbacks, however. The example cited above requires preconfigured information systems with certain reliability characteristics. Additionally, each of the VMs and their snapshots will consume resources on that system. Another obstacle is that students will have to get familiar with the VM environment and its functionality. Finally, virtualization is predicated on ease of access to high-speed internet. Areas that are under-served or lack reliable internet will need to adjust this method accordingly.

4.3 Vignette—online virtualization in an introductory cybersecurity course

The introduction of COVID caused a shift in how an introductory cybersecurity course at our institution was taught. Prior to COVID, students would attend in-person classes in a Linux lab. However, with remote learning and social distancing measures, in-person lab sessions were no longer possible. To accommodate this change, the course implemented virtualization. Each student was given access to an online VM running the Linux operating system, allowing them to conduct the same activities as they would in the physical lab. The use of virtualization also provided the instructor with better control and visibility over the classroom, as they could access each student's VM through the management panel of the virtualization software. Figure 3 shows a snapshot of the management panel and general status of one student's VM. Another benefit of virtualization was that students could log in to their VM at any time and were not limited by lab hours. The system worked so well that even though the course has returned to fully in-person learning, the Linux portion of the class still uses VMs.

Some common virtualization tools are listed in Table 1.

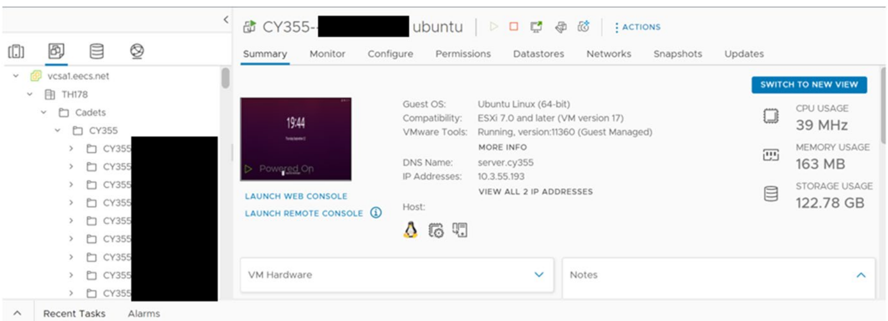

Fig. 3 Using virtualization technology to remotely view a student's work

Table 1 Virtualization Software Options

Microsoft Hyper-V
vSphere
V2 Cloud
VMware Fusion
SolarWinds Virtualization Software

5 Digital instructor notes

Chalkboards have a long history as an effective teaching aid. Communicating information visually helps students understand the lesson material and the process of writing on the board helps instructors maintain an appropriate pace. As a drawback, an instructor's drawing ability limits the complexity of the information chalkboards can display. Presentation software such as PowerPoint, Keynote, and Google Slides allow for complex images, animations, and other methods for presenting information. In many undergraduate classes, digital slide-based lectures have largely replaced chalkboard lectures. Interestingly, studies have found little difference in terms of effectiveness between the two (Seth et al., 2010; Szabo & Hastings, 2000). In fact, a study by Xingeng et al. (2012) found that the majority of students (81.7%) preferred a combination of both PowerPoint presentations and traditional "chalk-and-talk" lectures.

Fortunately, modern technologies make it easy to combine slides with digital "chalk-and-talk." In particular, a feature common to both presentation and most productivity software is a "pen" mode that permits digital writing on documents via a stylus and touchscreen interface. While digitally writing on a screen is not new, historically, many teachers never completely embraced technologies such as smart boards. Teachers cited not understanding how to use the technology as a primary reason (Korkmaz & Cakil, 2013). However, modern touchscreens, styluses, and software advances now allow for intuitive writing on digital documents. During COVID, teachers of all types learned to use these technologies. As a result, some instructors at our institution now prefer combining slide-based lectures with digital "chalk-and-talk" for in-person classes.

5.1 Vignette—digital writing on lecture slides

In response to social distancing requirements during COVID, our institution shifted to a dual classroom format that featured synchronous teaching. Some students attended in person while others simultaneously participated remotely (Williams et al., 2021). To cater to both the in-person and remote audiences, instructors in an introductory information technology course adopted Wacom tablets to replace whiteboards. The tablets were used to write on slides during class. The slides were displayed simultaneously to in-person students via a classroom projection system and to remote students via a screen-sharing feature in video conferencing software. Figure 4 shows an example of a teacher's "chalk-and-talk" lecturing technique. Instructors who had primarily given slide-based lectures interspersed

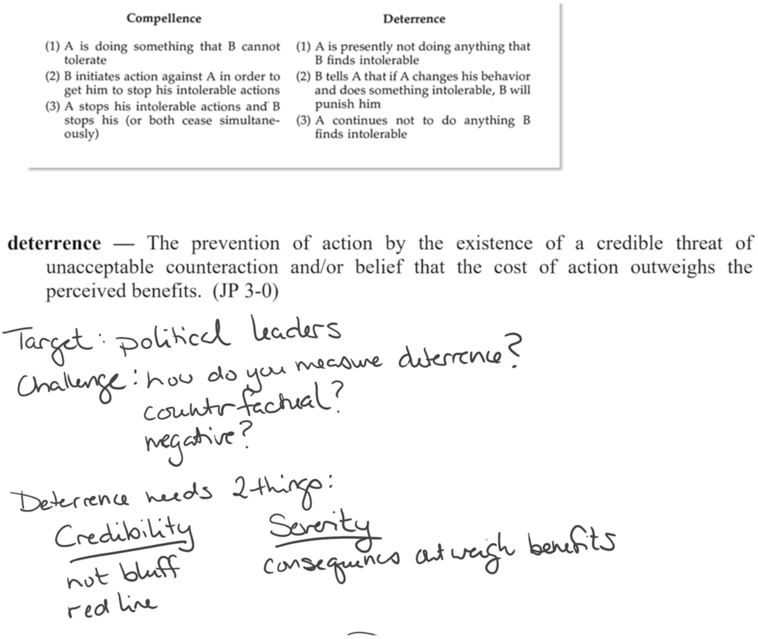

Fig. 4 Example of a combined "chalk-and-talk" digital whiteboard where instructors can write in comments on their slides during class

with writing on whiteboards with dry-erase markers before the pandemic became enamored with digitally writing on slides and continued the practice after returning to fully in-person classes. To support these efforts, our institution's computing department installed tablets in each classroom where the course is taught.

There are several benefits to writing on slides as opposed to writing on a whiteboard or just using slides. For one, digital writing can be saved, allowing for distribution to students after the class. If distributed, students do not have to take notes during class and can concentrate on listening to and understanding the lecture's content. Further, the slides sometimes contain diagrams and charts too complex to easily draw on a board that the instructor wants to annotate for the benefit of the class. Finally, writing on slides also helps the teacher with pacing, helping prevent an instructor from presenting information faster than the students can absorb it. Although it takes some getting used to for instructors, digital writing on lecture slides combines the benefits of presentation software and "chalk-and-talk."

6 Remote classroom participation and collaboration

Throughout the COVID pandemic, instructors used videoconferencing software to teach courses. Students and teachers interacted through webcams, microphones, and online chats. These same technologies can enhance the post-COVID learning experience. Remote participation and collaboration tools provide access to resources such as non-local guest lecturers while allowing students or instructors to attend remotely, if necessary. Remote office hours can enhance instructors' accessibility. Table 2 shows several valuable tools to enhance remote classroom pedagogy.

6.1 Non-local guest lecturers

Guest lecturers for courses are often difficult to come by and even harder to schedule. Fortunately, instructors in higher education often maintain contact with experts in their field to help facilitate student learning. Remote participation tools expand the pool of available guest lecturers since travel, lodging, and time costs can be excluded from the equation with remote lectures. One of the survey respondents in our survey highlighted a guest lecturer who taught one lesson per semester. In previous semesters, the guest lecturer who did not live or work near the institution would have to plan a day for travel, stay overnight, then travel back to their home after the lecture. The lecture itself lasted less than two hours. With the COVID lockdowns, the guest lectured remotely. The cost of travel and lodging were completely removed, as was the associated inconvenience. Despite the return to in-person classes, the guest lecturer's preference is to continue to give the lecture remotely vice visiting in person.

In another example, a professor has relationships with several high-profile cyber experts and leaders. These individuals were willing to speak to students, but scheduling and travel to the institution were only sometimes feasible. The experts now have a much more accessible option by "visiting" remotely. A side benefit of the remote option is that the audience size is not limited by classroom seating capacity. The number of people attending the talk is often *increased* since the virtual audience capacity far exceeds the constraints of limited physical space. Interested faculty and students outside of the class can now attend virtually. Using this practice, the professor reported that last semester, his students in New York received guest lectures from speakers in England, Canada, Virginia, and Georgia.

One note of caution: guest lecture sessions, especially if open to a wider community, should be carefully controlled. There are multiple reports of Zoom sessions and even Teams being "hijacked" by malicious actors. Common remediation techniques

Table 2 Remote Classroom Tool Options

Tablets and Digital Pens	Wacom One
	iPad
	Microsoft Surface
	Samsung Galaxy
	XP-PEN Star03 V2
Cloud-Based Collaborative Software	Microsoft 365
	Replit
	Google Docs
Meetings	Teams
	Zoom
	Google Meet
	Skype

include having a moderator on stand-by, requiring that messages be approved before appearing in the chat log, and only allowing the "host" to present material.

6.2 Attend class remotely

Before COVID, numerous reasons such as illness, travel, or poor weather could cause students or instructors to miss class, but the remote teaching practices initiated during COVID alleviate many of those issues. The COVID pandemic led to the widespread use of remote teaching, with both students and faculty adopting the associated technologies. Initially, classes were held fully online. Later, dual-teaching methods were introduced where some students attended in person while others simultaneously joined remotely (Stave et al., 2022). While blended teaching modalities are less effective than in-person classes, they offer a solution for avoiding canceled classes and may still be useful in some circumstances.

In our survey, several instructors shared their continued use of blended teaching methods. Even after the return to in-person classes, some students may contract an infectious disease and are then required to self-isolate. In these instances, the instructor still teaches the class in person for the remaining students; however, the potentially contagious student can (optionally) join the class remotely using video conferencing technology. The instructor shares their screen with the remote student and projects it for the in-person students to view. As discussed in Sect. 5, the instructor can digitally write on their tablet rather than write on a whiteboard. Though not ideal, the remote student is still able to participate in the lecture, join discussions, and even share their screen with the rest of the class, if needed. Thus, the remote student can still be a full participant in the class.

Much like a student attending class remotely, an instructor can also teach a class remotely. Before COVID, if an instructor could not attend in person, they either had to cancel the class or find a substitute teacher. Finding a suitable substitute could be difficult, especially for specialized subjects. Since COVID, remote teaching by the instructor has become a viable option. For instance, an instructor at our institution was requested to assist with an important government project several hundred miles from the institution. The instructor had subject matter expertise critical to the project's success. However, no one else on the faculty with both capacity and comparable knowledge could teach her upper-level software engineering course. Instead of canceling the class, the instructor taught remotely with an assistant in the classroom. The assistant prepared the room for remote teaching and monitored the students and technology during the class. The instructor presented the material as if they were in person and felt engaged with the class as they could see and interact with the students. Meanwhile, having the students in the physical classroom helped keep them focused and accountable.

This particular professor continues to use most of the technologies she used while teaching remotely now that she is back teaching in person. She combines some of the tools mentioned previously, such as digital whiteboards and screen-sharing, to make the class more immersive and ensure that students pay attention during the course. Figure 5 showcases an example of her digital whiteboard. She can share the digital whiteboard so the students can draw their explanations or answers to questions live while the whole class watches. As mentioned in Sect. 5, digital whiteboards can be recorded and saved for later purposes (without students having to take photos of the whiteboard), a capability that she makes use of. Additionally, she has students complete weekly assignments ahead of class. At the beginning of class, she randomly picks students to project their work through screen-sharing and then explain their thought process to the whole class. Though she initially implemented these practices as a remote teacher, she found them beneficial and brought them forward, so they continue to impact her teaching style now that she has transitioned back to in-person classes.

6.3 Remote group meetings and office hours

Pre-pandemic, in-person meetings were the norm, from office hours to project meetings. While in-person interaction is preferred, physical attendance is not always possible. Virtual meetings provide an alternative.

Office hours, one kind of meeting, are a key way for students to interact with instructors outside of class. Office hours are set for specific times and are traditionally conducted in person. However, circumstances sometimes make conducting in-person office hours at the set time difficult or impossible. Remote meetings can be a viable alternative.

Studies show students use remote office hours in a similar manner to in-person office hours but are more satisfied with remote office hours (Li & Pitts, 2009). While it may be tempting to return solely to in-person sessions post-COVID, instructors should consider offering some virtual office hours or allowing students to schedule

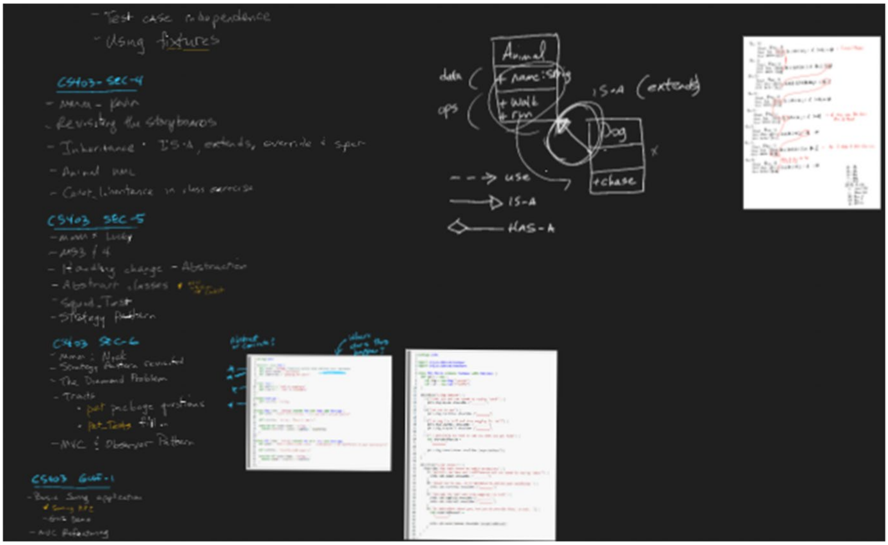

Fig. 5 Example of a digital chalkboard that an instructor shared with her students during class

remote meetings. As previously mentioned, screen-sharing technology and digital writing allow a remote student to view any materials an instructor wishes to show. Screen-sharing technology typically allows participants to transfer control of the screen to each other thus permitting the student to easily maneuver through a slide deck to point out the topics for which they require assistance. Embedded applications in video conferencing technology, such as Microsoft's Whiteboard, allow students and instructors to edit a shared canvas simultaneously. Users can also embed images, text, documents, videos, and web pages and make shapes such as circles and rectangles without having to draw them freehand. The app capability allows instructors to observe and correct the student's work remotely, further delve into a topic, or otherwise create tailored instruction for the student. Additionally, as illustrated in Fig. 6, the digital whiteboard created during a remote office hours session can be saved for the student to review and study.

As an example, an instructor at our institution reported using remote office hours while attending a conference. Although the instructor and student were several states apart, videoconferencing and remote screen-sharing technology enabled the instructor and student to conduct office hours. Figure 6 shows a screenshot of the session. A shared digital whiteboard allowed the instructor and student to simultaneously see, work on, and comment on a problem the student had difficulty solving. Interestingly, the instructor felt the session was more beneficial than a typical in-person meeting. With in-person sessions, the instructor noted their tendency to get frustrated by slow student progress resulting in them grabbing a marker and working

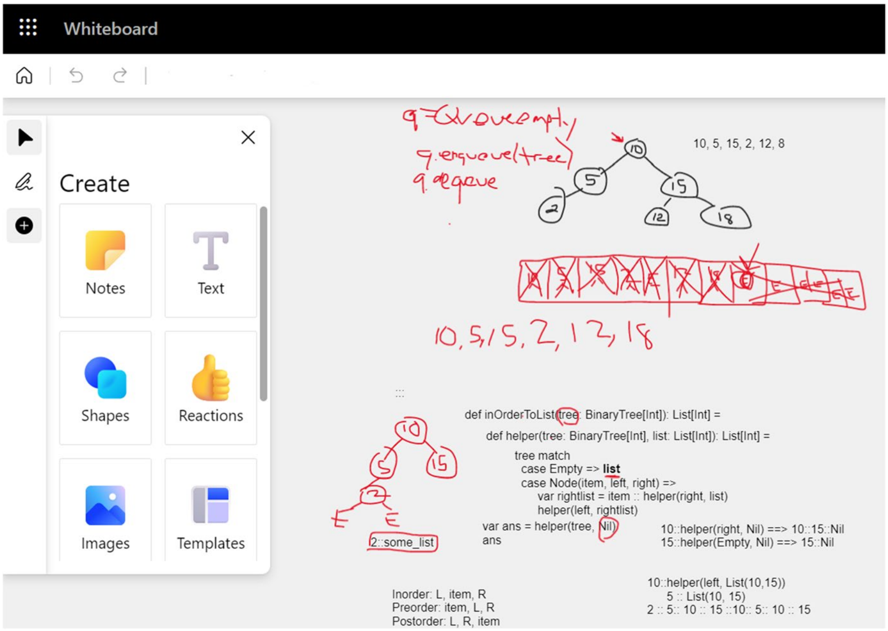

Fig. 6 A shared screen between an instructor and student working on a problem during remote office hours

out problems for the student. The remote session enabled the instructor to be more patient and provide gentle nudges to allow the student to work thru the problem at their own pace. The instructor did not feel impatient as they could work on other things while the student worked on the problem and asked for assistance only when they were at an impasse.

6.4 Considerations

There are important considerations to keep in mind with regard to even limited remote participation. Remote students reported lower motivation and engagement during the pandemic (Hobbs & Hawkins, 2020; Petillion & McNeil, 2020). Additionally, a recent study shows student preference for in-person learning (Williams et al., 2021). Therefore, efforts should be made to minimize remote participation. For a remote teacher or subject matter expert, we recommend the class attend in person, and only the presenter participate remotely. From our experience, for remote office hours or meetings, small groups of five or fewer participants are best.

7 A paperless classroom

For years, instructors have taught courses using Learning Management Systems (LMS) such as Canvas, Blackboard, and Moodle. These systems allow students to turn in assignments, access course materials, and participate in both graded and ungraded events electronically. However, before the COVID pandemic, many in-person courses that used an LMS still required students to submit paper assignments or take paper exams. COVID forced many courses to implement a paperless classroom. Teachers converted their paper assignments to an electronic format and had students submit them through an LMS. Likewise, teachers had to provide primarily digital feedback through features built into the LMS. For example, they had to digitally write on assignments using a tablet or touch screen or by writing on a physical printout and then scanning in the feedback. As one professor who took our survey stated, "Before COVID, nearly all homework and labs were collected as hard copy. Since COVID, they are all electronic submissions. I grade them by writing within the electronic files directly and return them electronically to the students. This also allows me to keep a copy of the graded work. Before COVID, homework and labs were due at the beginning of class. Now, all sections turn in assignments electronically via Canvas at the same date/time." Another professor stated, "I now maintain a fully digital submission/grading process and no longer use paper submissions for quizzes, lab reports, and problem sets."

For students, the shift to a paperless classroom with electronic submissions and feedback has several advantages over traditional analog methods. Students can receive reminders from the LMS as the deadline for submission approaches. Since assignments are typically released online for all students simultaneously, online submissions with the same due date for all students, regardless of their class period, equalize time constraints. Using an LMS for submission and feedback provides an organized location where students can view their feedback. When permitted, paperless classrooms can make collaboration among students easier as it can provide a shared collaboration space. Finally, instead of delayed feedback due to returning hard-copy assignments, instructors can provide feedback to students on graded submissions instantly, for example, via email or through the LMS.

Digital assignments also provide teachers with advantages. Teachers know exactly when a student submitted an assignment and can easily confirm which assignments were submitted on time. With a digital submission, the LMS also prevents the instructor from losing it. Finally, if instructors wish to grade assignments when they are away from their offices, they can grade the submissions without needing to bring paper copies with them.

While paperless classrooms can make administration easier, drawbacks exist. As discussed in the next section, cheating might be easier. Digital collaboration makes it effortless for students to share solutions. This is only a minor downside since students could already exchange and distribute digital or hard copies of their solutions. Paperless classrooms may also exacerbate the digital divide as some students may need access to computing devices, internet connectivity, or technical support. Additionally, some students may not have access to a stylus and tablet, or scanner, or be comfortable using them. Again, this minor consideration affects only a small group of students. Further, apps allow students to scan documents into PDFs using their cell phones. Finally, if instructors do not have precision digital writing equipment (or they are not comfortable using it), they may end up printing, annotating, and scanning the assignments, adding more workload instead of reducing it. Overall, the shift to paperless classrooms resulting from COVID has many advantages for students and teachers, but it is important to recognize that the technology may not be accessible to all populations.

8 Digital dishonesty

Moving to paperless classrooms increases concerns involving academic integrity. In particular, graded events administered digitally present a challenge to the academic integrity of a course. Digital dishonesty can be hard to detect. Studies show that people are more likely to cheat when the perceived benefit is sufficiently large relative to the perceived chance of being caught. COVID, in particular, provided such an environment and resulted in increased cheating (Bilen & Matros, 2021).

Therefore, it follows that to minimize digital dishonesty, one must (1) lower the perceived benefit and/or (2) increase the perceived chance of being caught. Fortunately, digital tools can assist with both. Table 3 provides a list of software designed for promoting academic integrity. For example, a course at our institution gives exams via an online LMS. To limit the perceived benefit of looking at another student's computer screen, most exam questions are chosen randomly for each student from a pool of available questions. No two students have the same exam. The instructors make sure students understand the random nature of question selection before the tests so that they will understand the limited benefit of trying to cheat by copying another student's answers. During COVID, the course began requiring

Table 3 Tools for Promoting Academic Integrity

Online Proctoring	Lockdown Browser
	Respondus
	Honorlock
	Proctorio
	Talview
	Examity
Plagiarism Prevention	MOSS
	Codequiry
	Turnitin
	SafeAssign

students to use a lockdown browser while taking exams to prevent unauthorized online material. A lockdown browser prevents students from going to any prohibited websites and stops the exam if students minimize or close the browser. Several exam proctoring services offer lockdown browsers, with Table 3 listing some of the providers. Post-COVID, the course continued using a lockdown browser to help prevent cheating because with over 500 students per semester taking the course, it is otherwise difficult to monitor all students' web access during an exam.

Outside of exams, it is trivial to copy electronically submitted graded events. Students can easily share essays or other written products via email or text. Likewise, students can cut and paste elements of published works. Fortunately, instructors can use electronic tools to check essays and written content for plagiarism. Further, specific disciplines have developed plagiarism tools designed for use within that area. For example, instructors of computing courses can use MOSS (Measure of Software Similarity) to check for similarities in computer programs. There are other innovative ways to deter and detect dishonesty. As an example, a course at our institution gives each student a unique base file for use in a project. The file is digitally watermarked, allowing instructors to detect if one student is submitting a file originally given to another student.

Recently a new threat emerged that may spur digital dishonesty. Recent advances in artificial intelligence make computer-generated answers virtually indistinguishable from those of humans. Future research, discussed in Sect. 10, must address what precautions an instructor can or should take against such tools.

It should be noted that instructors and departments should make a conscious decision on how they will use tools that can detect digital dishonesty. While intended to detect cheating, they may be more powerful when thought of and used as tools to promote academic integrity. Our department has committed to a policy focused on preventing cheating. On the first day of class, the students are introduced to the detection tools used in the class. Further, they are told how the tools work and why they are difficult to defeat. Then, during the semester, instructors tell the students which assignment the tools will be used on for the first few uses. Afterward, students are no longer explicitly told which assignment the tools will be used on, rather they are told the tools may be used to detect dishonesty on all remaining assignments. While it may seem counterintuitive, informing students which tools a course uses, how the tools work, and when the tools are being used helps increase the student perception that they will be caught and thereby promotes academic integrity. Additionally, the use of these tools is designed to supplement other academic integrity practices, such as fostering a culture in the classroom that discourages cheating and the careful creation of assignments.

9 Support considerations

This paper has shown that digital practices and technologies implemented during COVID can open new avenues of teaching styles and methodologies. Unfortunately, several underlying conditions must exist for remote technologies to succeed. Some of those considerations have been listed throughout the vignettes above.

9.1 Infrastructure and equipment

For most of the practices discussed, the classrooms and common areas should support stable, high-speed internet to enable real-time collaboration. This may be particularly difficult in a classroom environment as a large portion of the institution is likely conducting classes during the same time periods. Before widespread adoption, institution technology groups should be consulted to ensure that the networks can support the expected streaming traffic. Not having a stable, high-speed internet connection can disrupt these practices so much that the technology becomes a detriment to the classroom experience rather than a supplement.

Other infrastructure necessities depend on the particular practice. For instance, hosting VMs for the students to work on often requires dedicated servers or leased cloud space. Digital chalkboards or tablets often need special hardware in the classroom to work effectively. While instructors can always purchase their own tablets, having institution-provided tablets has been a tremendous asset in terms of both warranties and technical support.

9.2 Institutional support

Additional support that is useful to consider is institutional backing in the form of training and technical support. Technical support helps alleviate frustrations that are common with adopting new technologies (Alshammari et al., 2016). While individual professors can implement some of these practices independently, having institutional support can lead to better and more consistent outcomes. In our experience, training helps instructors feel more confident in the technologies, increases adoption, and helps create and disseminate best practices across the institution. Training can be formal, through prepared classes, or informal such as through lunchtime guest speakers and group discussions. The training can be adapted to the specific needs of the department and varies by practice.

9.3 Maintaining proficiency

As the world continues to grow more and more connected, it is our view that future pandemics and other crises may cause a return to environments similar to the COVID lockdown. Thus, it would be in the best interest of both instructors and students to remain proficient in these practices. Utilizing the technologies and practices from above could help make the transition back to a fully remote environment easier as the technologies will be familiar to both instructors and students. At our institution, teachers are encouraged to teach one to two lessons each semester remotely to maintain these competencies.

10 Future work

As teachers increasingly integrate technology in their classrooms, they will likely collect more data. While it is important to implement appropriate safeguards for this data, several ethical considerations must be addressed. For example, there is a question of how long data should be retained and whether older submissions should be re-evaluated (perhaps years after the initial submission) using new technologies that can detect digital dishonesty more effectively. Additionally, there are privacy concerns to consider, such as whether students have the right to have their submissions deleted after a certain period of time. These are important questions that will need to be explored in future research.

As the educational community explores ways to modernize the classroom, it's essential to consider the impact of advanced AIs like ChatGPT. Educators must weigh the benefits and drawbacks of incorporating such technology into instruction. On the one hand, it may become a valuable tool for students and teachers, much like the introduction of personal computers. On the other hand, over-reliance on AI could hinder the development of critical thinking and problem-solving skills which are key goals of higher education. Students may submit AI-generated answers without fully understanding the material. Furthermore, widespread use of AI may result in a singular perspective in the classroom—the AI's perspective—leading to a reduction of diversity in ideas and perspectives, thereby limiting opportunities for students to expand their thinking. Future work must examine how to effectively integrate AI while maintaining desired learning outcomes. Other authors, such as (du Boulay, 2016; Mejia & Sargent, 2023; Zhong, 2023) have discussed these topics in greater detail.

As technology advances, educators must adapt to new developments in the field. While advanced AI is one area, other cutting-edge technologies must also be considered. For example, companies are investing heavily in the development of augmented and virtual reality, which have the potential to create fully immersive and interactive virtual environments. This could bring new opportunities, and challenges, for instruction. Additionally, while some teachers have incorporated gamification and data-driven instruction into their classrooms, their adoption is far from universal. More research is needed to evolve pedagogy to fully take advantage of 21st-century technologies.

11 Conclusion

The COVID pandemic led to advancements in technology, pedagogy, user capabilities, and preferences. Initially, educators were forced to teach remotely, but now higher education has returned to an in-person learning environment. However, technologies and practices used during the pandemic should still be utilized to improve education. Through surveys and faculty interviews, four key practices were identified for post-COVID in-person classrooms: online student activities, digital instructor notes, remote classroom participation and collaboration, and a paperless classroom.

Instructors can use online resources to monitor students, assess their understanding, and provide real-time feedback. They can enhance their lectures by combining the powerful visualizations of presentation software with the educator insights offered by digital instructor notes. They can permit appropriate remote participation and collaboration, thereby increasing accessibility. Finally, instructors can adopt a fully paperless classroom for efficient submission, testing, and feedback processes.

Some considerations must be addressed when embracing the post-COVID classroom. In particular, institutions must take active steps to limit digital dishonesty and build the required infrastructure. Educators must also maintain proficiency with the technologies, especially to be prepared for any further crises. Additionally, emerging technologies, especially involving AI, present new opportunities and challenges that require thoughtful consideration and for which no consensus has yet emerged.

Overall, embracing and integrating the practices and recommendations discussed in this paper will holistically improve the post-crisis, in-person learning experience for both the student and the teacher, thereby allowing us to progress forward post-COVID in higher education.

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Data Availability The only dataset generated and analyzed during the current study was used to create Figure 1 but is no longer available.

Declarations

Conflict of interest None.

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