# COVID-19 pandemic student engagement strategies for materials science and engineering courses

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In immediate response to the COVID-19 health emergency, the Materials Science and Engineering (MatSE) department at The Pennsylvania State University (Penn State)—similar to most educational institutions around the world—followed health experts' advice to quickly pivot from in-person instruction to remote instruction in an effort to prevent the spread of the virus. This means all learning activities that have conventionally taken place in classrooms, such as lectures, seminars, and laboratory practices, were adjusted accordingly during the academic years of 2019–2020 and 2020–2021; the modification of teaching methods started in March 2020.

Although remote instruction uses online teaching tools to guide teaching, many institutions like Penn State made a distinction between *online* and *remote* teaching. Online instruction refers to when a planned curriculum is intentionally developed for delivery through different web-based platforms.[1] Research has shown that online instruction can allow students to have a flexible schedule (when delivered asynchronously), encourages students' self-motivation, allows for the advancement of written and virtual communication skills, and improves accessibility to class content.[2] However, there can be challenges associated with online learning such as the potential for reduced interaction between the student and teacher (especially outside of the formal online classroom), limited access to the Internet, and lack of robustness of online teaching infrastructure such as specialized laboratory facilities and equipment that can be manipulated remotely.[3]

Remote instruction, on the other hand, refers to a delivery mode established as a temporary teaching measure due to difficult circumstances where instructors have limited time to adequately prepare course materials for online delivery.[1] Additional challenges present in the transition to remote instruction due to the COVID-19 pandemic include increased workload for both teachers and students, limited learning design support due to the scale of sudden need, mental health issues related to the sudden transition of courses to a remote environment, online security for exams, changes in the grading scale, and graduation timelines.[4]

Penn State has over two decades of experience working with online teaching platforms to enhance learning processes. It offers online degrees and certificate programs through Penn State World Campus, an initiative started in 1998 to serve distance learning.[5] The Penn State World Campus has been recognized in the *U.S. News & World Report*'s best online programs rankings.[6] In order to support the demand for online teaching, the university has developed a large number of learning design units, which are entities that support the design, development, and delivery of online course and degree programs and to also, in some cases, support faculty who teach online courses to resident students. The learning design unit that supports the MatSE department and the College of Earth and Mineral Sciences (EMS) is the John A. Dutton e-Education Institute. The Dutton Institute includes a team of learning designers, programmers, multimedia professionals, editors, and accessibility specialists who collaborate with faculty to create high-quality online, face-to-face, or hybrid courses in order to provide meaningful learning experiences for science-technology-education-mathematics (STEM) students.

During the pandemic, the Dutton Institute played an important role while the college rapidly transitioned to remote instruction. The Institute provided support through webinars, online tutorials, and one-on-one appointments to help faculty modify their course content and teaching strategies. Additionally, the university, with the input of instructors and learning design units, created the freely accessible website https://keepteaching.psu.edu, where faculty could find information about digital pedagogy, best practices to engage students, alternative grading approaches, templates to better communicate ideas to students, a schedule of technology webinars and tutorials, and a link to the Dutton Institute's freely accessible *Flexible Instruction Teaching Guide* (https://bit.ly/flextchng), among other resources.

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Technology resources recommended by the Dutton Institute, and adopted by the MatSE faculty, included Zoom, Kaltura, Canvas, and Google Workspace for Education (G Suite). Zoom was one of the most used tools by instructors for remote teaching during the COVID-19 pandemic, since it provided the option of communicating with students through video and chat in real time. Kaltura was used to record lectures and tutorials beforehand for students to be able to watch asynchronously. Similarly, Canvas is a learning management system used to access, design, and manage course content, providing students with easy access to course documents, lectures, and assignments. Finally, G suite and Microsoft Teams were used to foster collaboration among faculty and students.

The courses taught by MatSE required dynamic writing and drawing of equations, molecules, and vectors that would have taken a lot of time and effort to reproduce electronically for those new to tools such as pen tablets, whiteboarding apps, and the like. Therefore, most MatSE professors used platforms such as Zoom and Google Hangout to teach synchronously. However, to accommodate students taking classes in other time zones, the lessons were also recorded and made available to students to watch asynchronously. For laboratory classes, videos of the experiments were recorded using 360-degree action cameras (e.g., GoPro), and digital cameras to simulate the laboratory conditions. These videos were recorded beforehand and shown either synchronously during class or provided asynchronously. Finally, learning assessment activities, such as class discussions, quizzes, and exams, were designed to be proctored online by utilizing Zoom breakout rooms, where students shared their screens in real time with instructors and teaching assistants who could monitor the activities remotely.

Overall, the challenges associated with the remote transition also brought many opportunities, especially to those new to teaching online, that will most likely transcend the health emergency due to the current pandemic. Higher education institutions are recognizing the importance of online teaching and different student engagement strategies that allow for the integration of virtual learning with residential classes.

## Residential classes transition to remote instruction

The teaching modes during the pandemic evolved in order to accommodate the US Centers for Disease Control and Prevention (CDC) guidelines for COVID-19. The spring 2020 semester was entirely taught remotely, whereas teaching in the academic year 2020–2021 was done through a variety of approaches. Instructors could choose to teach in one of four modes during the pandemic: in-person (where physical distancing was possible), mixed-mode, remotely synchronous, or remotely asynchronous. Mixed-mode instruction offered a mix of in-person and remote teaching, wherein a portion of the students attended the class in person, and the remaining students attended the class remotely in a synchronous or asynchronous environment. The synchronous instruction was characterized by the interaction of students and faculty in real time through video and audio communication. On the other hand, asynchronous teaching encompassed activities that did not require the student and faculty to connect in real time.

Studies have shown the effectiveness of both online synchronous and asynchronous teaching in education.[7–9] Synchronous instruction can facilitate active participation of students in class; as a result, students feel connected instead of isolated.[7–9] Furthermore, studies have shown that synchronous remote instruction can promote higher grades when compared to in-person teaching, and can decrease the number of dropout students when compared with asynchronous courses.[7,9] In one study, the majority of students (60.6%) preferred synchronous learning, as it helped them to better understand the course content.[10] Despite the many advantages of this approach, disadvantages associated with synchronous learning include students' lack of punctuality and low student participation in class.[8] On the other hand, asynchronous instruction can be facilitated by tools such as email, learning management systems, social media, and recorded video lectures, among others. One of the biggest advantages of this approach is the flexibility it offers to the students. Research has also shown that asynchronous learning can increase a student's ability to process and analyze information, as well as improve time management skills.[10] Moreover, this approach accounts for possible modifications of guidelines during a pandemic and offers an alternate schedule for students in other time zones.

A spring 2020 end-of-semester survey conducted by Penn State's Teaching and Learning with Technology (TLT) unit revealed the challenges faced by faculty and students during the pandemic. This survey was taken by 576 faculty members and 3787 students. Results showed that the major challenges of Penn State faculty during the transition to remote learning included student learning (74%), the translation of in-person course activities to a remote environment (54%), communication with students (38%), online security for exams (33%), teaching evaluation (27%), and impacts to tenure eligibility (27%).[11] In order to overcome these challenges, the faculty used the following resources to teach their classes: learning designers (41%), IT help desk (37%), campus teaching & learning center (13%), and technical teaching assistants (6%).[11] The most used tool for the class content delivery was Canvas, followed by Zoom, Office 365, and G suite. Students' biggest concerns for the transition to remote learning were associated with learning (82%), learning assessment (69%), communication with faculty (46%), changes to grading structure (38%), and online privacy (30%).[12] Overall, only 9% and 12% of faculty and students, respectively, most of whom were new to online instruction, preferred remote instruction over in-person.[11,12]

The MatSE faculty, with the support of the Dutton Institute and the group tasked with ensuring continuity of instruction, developed a comprehensive plan to ensure quality teaching and learning experiences and increased student satisfaction. These units provided innovative strategies and tools that have been used to increase students' engagement in both online and face-to-face classroom settings. The Dutton Institute provided teaching and learning support, whereas TLT provided physical resources such as laptops and tablets through technology loaner programs to ensure students' learning. The Dutton Institute shared many different tools and pedagogical strategies that instructors could use to improve the quality of teaching and learning. Some of these tools included the use of the EMS Faculty Studio, a space equipped with Lightboard technology (**Figure 1a**) that can be used to record demonstrations and interviews. The Lightboard studio includes a clear glass panel and a digital recording setup and "mirroring" software that enables the professor to use traditional "whiteboard" teaching methods (e.g., working through equations, sketching illustrations) while not turning one's back on one's students. Another tool given to instructors that enabled them to retain familiar student engagement strategies was the use of digital tablets for annotating items such as presentation slides, as shown in **Figure 1b**. Direction was also given to instructors teaching mixed-mode classes in the use of a variety of technologies to engage students.

## Mixed-mode laboratories

The MatSE department adopted the approach of virtual laboratories during the COVID-19 crisis. Practical experience in the laboratory plays an important role in materials education. However, the hands-on experience portion of the laboratory had to be modified, due to the limited in-person capacity to comply with the new safety and health regulations. As a result, remote laboratory instruction necessitated using different methodologies to simulate experiments, such as video-recorded demonstrations (**Figure 2a**), written description of experiments assisted with photos (**Figure 2b**), live demonstrations, software tutorials (**Figure 2c**), and interactive discussion boards. To complete laboratoary reports, whether in person or online, students were provided with videos, images, and data sets collected by the instructor and teaching assistants on which to base their observations and statistical analysis. Furthermore, all video recordings were made available to the students as reference materials so they could complete their assignments. MatSE 460 and MatSE 462 are courses associated with materials laboratory characterization and general properties of materials, respectively. For each course, students were given the opportunity to choose either residential or online sections to accommodate their learning preferences during the pandemic. MatSE 460, the materials characterization class, was offered in fall 2020 to 87 enrolled students. In this class, 56% opted for in-person instruction, whereas 44% selected remote instruction. On the other hand, in spring 2021, MatSE 462, which has a prerequisite of MatSE 460, showed an increase in the number of students willing to take the class in person, with 68% of the students taking the class in a residential manner and 32% of the class taking it online.

The online mode of instruction in the laboratory components of courses was implemented for students who did not feel comfortable attending classes on campus and/or for students taking the class in other countries with different time zones. The students who decided to take the in-person sections were directed to follow strict safety regulations to promote mask wearing and physical distancing. Students and

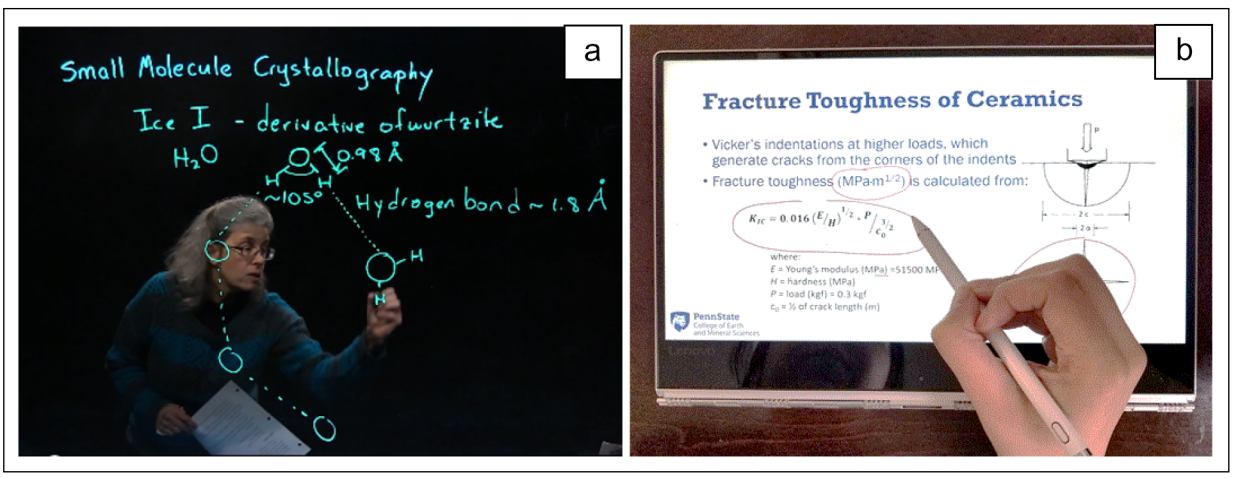


**Figure 1.** Examples of different teaching styles used by professors in the Materials Science and Engineering department at Penn State. (a) Crystal Chemistry lesson explained on a Lightboard during the summer semester of 2020. (b) Tablets provided by the Penn State Teaching and Learning with Technology unit intended to act as a whiteboard to explain the concept of fracture toughness.

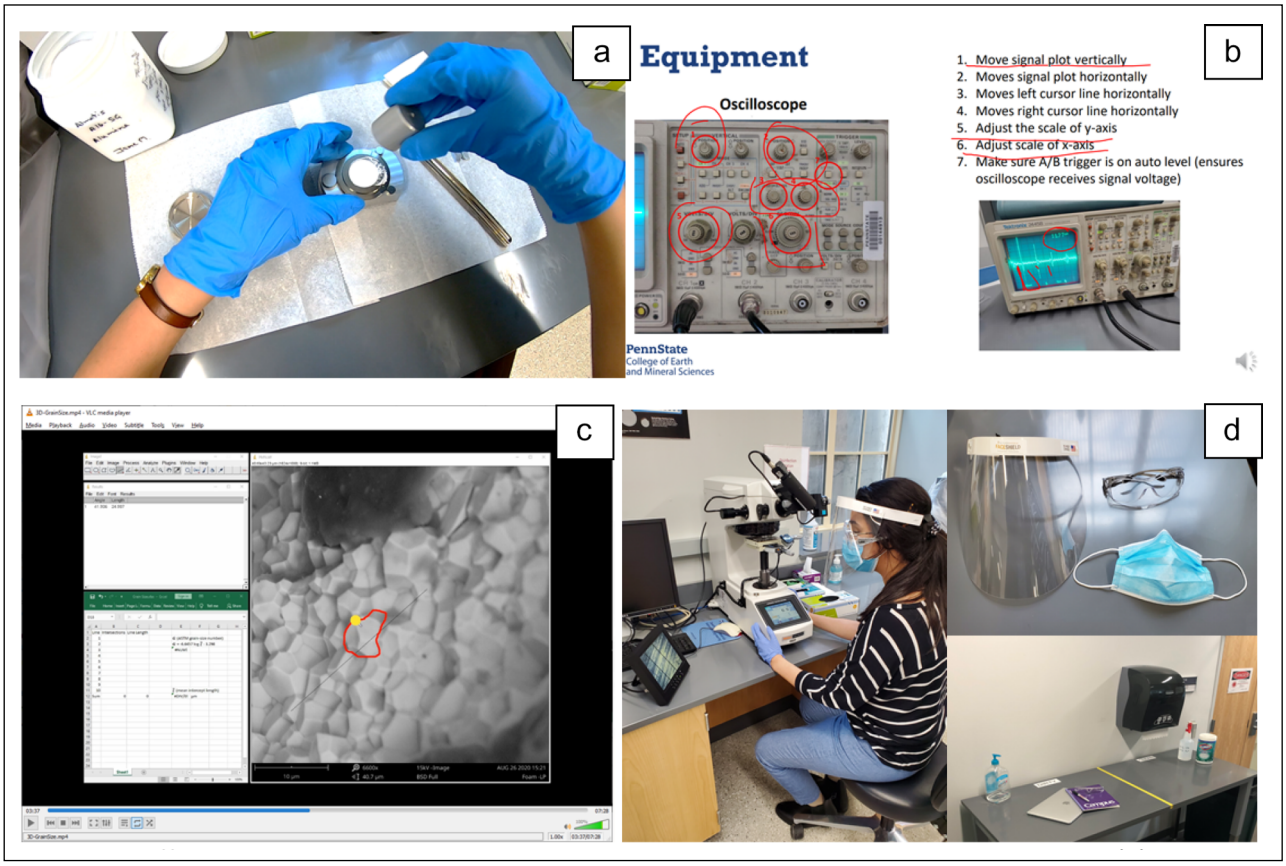


**Figure 2.** Different approaches taken in laboratory courses during the COVID-19 pandemic. (a) Video demonstration of sample preparation for x-ray diffraction using a 360-degree action camera. (b) Detailed description of an oscilloscope for the ultrasonic analysis of elastic properties in metals. (c) Video-tutorial of the grain measurement based on the American Society for Testing and Materials (ASTM) standards in a piezoelectric sample. (d) Personal protective equipment (PPE) used in the laboratories by students, faculty, and teaching assistants for residential classes. Left, laboratory participant using a Vickers indenter wears a face shield, goggles, gloves, and a mask. Upper right, PPE used in the laboratory. Lower right, disinfection stations placed at the entrance of all laboratories.

instructors used masks at all times in hallways, classrooms, and laboratories. Disinfection stations were also placed in each lab, and students were directed to wash their hands and clean their belongings upon arrival to the laboratory (**Figure 2d**). The disinfection stations contained an aqueous solution in spray bottles with up to 90% v/v isopropanol, paper towels, and disinfectant wipes. Once in the lab, besides wearing a mask, students were required to wear goggles, gloves, and face shields as PPE elements to protect them against the virus and the materials utilized in the experiments conducted in class (**Figure 2d**). With all these security measures in place, students expressed feeling safe in the laboratories, which might explain the increase in the number of residential students taking the laboratory class of MatSE 462 in spring 2021. Some of the change in preference to in-person offerings could also have been due to the changing reaction to the pandemic itself, with many students eager to return to "normal."

## Remote classroom assessment strategies

Remote and mixed-mode instruction also necessitated an adjustment in the conventional classroom assessment strategies used in residential classes. One of the biggest challenges while transitioning to remote learning was creating an interactive environment conducive to significant learning. As a result, in-person assessment techniques were adapted to an online learning environment while keeping these techniques both flexible and rigorous. Strategies used in the MatSE department during the pandemic included short answer and multiple-choice quizzes and exams with large question banks, essay and research paper activities, presentations, poster presentations, group discussions, student participation, take-home and proctored exams. During the pandemic, instructors who relied on exams and quizzes to assess students' knowledge came up with new ways to promote student learning while preserving academic integrity. Some instructors chose to post long-format argumentative exams in Canvas and impose time limits. This approach did not allow for direct proctoring but mitigated students' violations of academic integrity policies. Another strategy to preserve academic integrity was to use Zoom

to proctor exams through the student's use of cameras and audio while taking an exam. Using this methodology, the proctor had access to the student's sound, webcam, and computer desktop screen. For large classes, breakout rooms were enabled in Zoom. This allowed instructors to create groups of up to 50 participants, with a proctor or teaching assistant assigned to each section of the class. In addition, short-format exams and multiple-choice quizzes were hosted on Canvas. Students were able to take tests from randomized question banks during a specific time frame.

Presentations and group discussions were carried out both synchronously and asynchronously. Synchronous project presentations were made mainly through Zoom. As mentioned before, this platform allows the student to share a presentation with the class and receive timely feedback from peers and professors, just as they would in a face-to-face setting. Similarly, group discussions in class were conducted using breakout rooms. In this case, the instructor would visit the breakout rooms and monitor each group's understanding of the class content. Presentations were also done asynchronously. The students used PowerPoint, microphones, and cameras to record their slideshow, then uploaded their presentation recording to platforms such as Canvas or G Suite. The main advantage associated with asynchronous presentations was the benefit of being able to create and practice the presentation according to the student's schedule. Some presentations were based on essays and research projects. Homework and exam instructions, papers, and reports were distributed in class, and students would turn in their assignments online. Feedback was given to the students through email and annotated comments on their papers. The "SpeedGrader" feature in Canvas allowed the instructor or teaching assistant to view students' digital submissions and provide feedback either by text comments, video, or audio directly on their submission, as well as the grade.

One of the activities that combined both a technical writing component and a group discussion was the annual Undergraduate Poster Competition. During the pandemic, the poster presentation for the class "MatSE 492 W: Materials Engineering Methodology and Design" was evaluated through Zoom breakout rooms. The judges were placed in a breakout room at a specific time, where they would listen to the presentation and ask questions of the presenters.

## Summary

Overall, the COVID-19 pandemic exposed both weaknesses and strengths in our current education system. The inclusion of digital tools to complement and enhance higher education proved to be highly effective, as was Penn State's early investment in learning design. Consequently, while there is a wealth of research and expertise related to educational models that blend residential and online environments and teaching strategies, more resources need to be directed toward continuing research and toward professional development efforts in order to achieve a robust education system in the "new normal."

During the pandemic, there was strong collaboration between the instructors and learning designers; this partnership is likely to continue in this "new normal" due to the promise of mixed-mode teaching in the future in materials science and engineering. The pandemic also highlighted the importance of adopting diverse methodologies for teaching materials science and engineering based on advancing technologies for both new and time-proven pedagogical strategies that emerge from the field of learning science. Conventionally, education in materials science and engineering has required students to learn different concepts in the fields of physics, chemistry, design, and computer science in an integrated manner. This emergency has shown us the importance of online tools and pedagogical strategies in both teaching and learning, and their role in intentionally designing meaningful learning experiences that allow universities to keep educating students to produce the next generation of engineers, scientists, and pioneers.

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