

# Online Engineering Education in Response to COVID-19: Overview of Challenges in the United States and Proposed Active Learning Strategies\*

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The COVID-19 pandemic forced many Colleges and Universities across the globe to deliver education online. This online switch was abrupt and challenging for both students and instructors. Here we summarize the challenges faced in the United States at the University of Illinois at Chicago (UIC) College of Engineering during online teaching in Spring 2020 as a result of the COVID-19 pandemic and provide recommendations for the online delivery of classes. To understand the challenges faced, surveys were administered to UIC engineering students ( $N = 580$ ) and instructors ( $N = 93$ ). Two student focus groups were also convened ( $N = 56$ ,  $N = 40$ ). After the shift to online education, UIC students wanted to be on campus but not if that posed a risk to their or their family's health. Students also perceived lower quality of education after the shift. UIC College of Engineering instructors felt mostly prepared to transition online but were concerned about student learning assessment methods. Most instructors felt their classes went well and, if their classes were online in Fall 2020, planned to teach them with at least some amount of asynchronous delivery. Whenever possible, we recommend a blended approach to online teaching, offering the flexibility of asynchronous content with the engagement of a synchronous class. Other specific recommendations for lab classes, fostering a sense of student community, and student

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learning assessment are provided to address concerns and challenges as indicated by those surveyed. Given the unknown future epidemiological changes and willingness or the ability of students and instructors to return to campus, it is prudent to prepare for online learning in a COVID-19 world. We provide definitions, examples, considerations, and suggestions to assist in the online delivery of classes to guide and assist in this preparation.

**Keywords:** COVID-19; engineering education; online learning; teaching tips; blended learning

## 1. Introduction

The COVID-19 pandemic caused many Colleges and Universities to suspend in-person instruction during the Spring of 2020 and immediately resort to online learning. Online learning (today largely synonymous with electronic- or e-learning) has been a burgeoning domain since the late 1990s [1, 2]. While online learning approaches and pedagogy have been well documented, these techniques can also be combined with in-person learning – an approach referred to as blended-learning (b-learning) [3]. B-learning techniques may be incorporated into higher education and have been demonstrated to be advantageous compared to traditional in-person learning [4–5]. More recently, and with the advent of affordable “smart” devices, mobile-learning (m-learning) has also emerged as an educational modality [6]. However, despite these advancements in teaching and learning, institutions of higher education in the United States tend to utilize traditional in-person lecture-based learning. In fact, in 2018, nearly 65% of US students at degree-granting postsecondary institutions do not engage in any distance learning [7]. Thus, the switch to online learning during the COVID-19 pandemic was an unprecedented challenge for higher education students, staff, and instructors.

At the University of Illinois at Chicago (UIC), the College of Engineering initiated an Instructional Delivery Planning committee in late Spring 2020 to evaluate the transition to online instruction and prepare recommendations on the best approaches for classes in Fall 2020 and beyond. UIC is a large Research I institution located in an urban setting that serves over 33,000 diverse students, with many commuting to campus. This paper summarizes the challenges faced by students and instructors during the Spring of 2020 and provides recommendations for the delivery of lecture and laboratory classes, student learning assessment, and fostering a sense of community among the students under rapidly changing COVID-19 conditions. This report represents input from students and instructors in all engineering departments at UIC, including bioengineering, civil & material engineering, chemical engineering, computer science, electrical & com-

puter engineering, and mechanical & industrial engineering.

## 2. Challenges Faced

The abrupt switch from in-person instruction to online-only learning presented many instructional delivery challenges. At the end of the Spring 2020 semester, UIC, the College of Engineering, and various committees conducted several surveys to assess these challenges as part of ongoing quality assurance/quality improvement efforts. The surveys were mixed-method and consisted of short answer, Likert-scale, and multiple choice questions. Surveys were administered by either Qualtrics or Google Forms and were completed anonymously by students and faculty. Small student focus groups were also conducted to gather student input in a less restricted manner. Questions to students included: experience during the online transition (e.g., staff and faculty guidance, concern, and support), worry and stress (e.g., educational, financial, and healthcare stressors), student services (e.g., administrative support), academic issues and concerns (e.g., grades, personal motivation, learning from home, access to internet, work-life balance), satisfaction with online transition, and technology utilization. Questions to faculty included: teaching practices (e.g., content delivery, tools used, assessment type), lab practices, teamwork and engagement practices, offering of office hours, expected teaching modality for future, adequacy of support (e.g., training, workshops) provided from the institution, and adequacy of resources (e.g., hardware, software, other tools) provided from the institution.

### 2.1 Student Challenges

Students from the College of Engineering (N = 580, ~76% undergraduate, ~21% graduate, ~64% male, ~36% female) reported being stressed during the Spring 2020 semester in ways they had not previously been. For example, students worried about losing friends and personal connections (72%), paying their bills (80%), having access to healthcare (54%), and consequences of the spread of COVID-19 (92%). Students also faced several academic issues, including finding the motivation to complete coursework (66%), balancing school and family (56%), finding a quiet place to study (51%), taking

courses that were not translated well to remote learning (50%), not learning as much as in-person (55%), finding time for participation in synchronous classes (32%), or even accessing reliable internet (31%). Most students (58%) perceived a decrease in the quality of education. However, students were predominately comfortable with the technology utilized during the shift, like Blackboard (a learning management system - LMS), Zoom (a teleconference program), and Webex (a teleconference program).

In small focus groups (N = 56 students, ~73% undergraduate, ~27% graduate; and N = 40 students, ~78% undergraduate, ~22% graduate) with students from across the entire university, students expressed a desire to be on campus and part of a larger “community”. However, students were hesitant to return to campus and wanted their health, safety, and privacy to be paramount. Overall, students supported online learning for Fall 2020 if that decision prioritized addressing those concerns.

## 2.2 Instructor Challenges

Instructors from the College of Engineering (N = 93) reported that most (69%) felt prepared for the online transition, with 49% training themselves for the switch. Most had the necessary software (88%) and hardware (59%) for the switch as well. Regarding content delivery, 47% of instructors delivered synchronously only, 9% delivered asynchronously only, and 44% delivered a blend of the two. Here, synchronous referred to content delivery wherein students needed to simultaneously attend online lectures and asynchronous referred to content delivery wherein students were not required to simultaneously attend online lectures as they were available outside of class-time. Student learning assessment was a concern among instructors. Various methods were used to assess students after the online switch: 31% used only asynchronous (e.g., homework assignments or open-schedule exams), 34% used only synchronous (e.g., traditional class exams with online proctoring), 11% used both and 16% used projects only. The majority of instructors indicated that they need to redesign assessment for their course if classes would be delivered online in Fall 2020. Further, instructors indicated they were looking for training or recommendations on assessment methods. Once online, lab content was delivered either by pre-recorded videos, data sets, or simulations. Half of the instructors had teamwork/teaming components in their courses and 83% were able to keep the same teaming structure after the transition online. Overall, 68% of instructors were satisfied with their online teaching. If Fall 2020 classes were to be online, instructors are planning

to deliver their classes as synchronous-only (42%), both (42%), and asynchronous-only (16%).

## 3. Recommended Approaches

Given that future epidemiological changes of COVID-19 are uncertain, in-person instruction during an active pandemic may be precluded. Further, the risk presented to students and instructors is relative and depends on an individual's circumstances, including pre-existing conditions and family considerations. It is plausible that a significant number of students and instructors may be unable to, or may choose not to, return to campus while COVID-19 conditions persist. Therefore, we recommend planning for online teaching as a supplemental or optional form of education, if not as the sole method, during the active pandemic. This recommendation is supported by UIC students who favored online education if that prioritized their health and by engineering instructors who were largely happy with online education. However, there were several challenges that students faced which led them to perceive a decrease in the quality of education after transitioning to online teaching and learning. Thus, it is prudent to prepare the most compelling and appropriate strategies for online learning. Teaching online requires a number of adjustments, especially in terms of student motivation, engagement, and assessment. Leveraging the survey and focus group data along with contemporary literature, the following options and recommendations for online learning are outlined.

### 3.1 Lecture Classes

Three forms of online teaching and learning are proposed, as summarized in Table 1. Best practices for these forms are provided graphically in Fig. 1. For asynchronous teaching, content traditionally delivered via an in-person lecture is now delivered via short videos. Videos can be prepared using cell phones or USB webcams, edited (e.g., OpenShot, Echo360, Camtasia, iMovie, Adobe Premiere), and uploaded to personal websites, YouTube or LMS like Blackboard or Canvas. These videos may be paired with an assessment to check that students have watched and understood the video content (e.g., Panopto). Instructor-student and student-student interactions occur via online forums (e.g., Piazza, Blackboard Discussion Forums), online office hours via web conferencing tools (e.g., Webex, Zoom, Microsoft Teams), instant messaging (e.g., Slack, Microsoft Teams), and email. For synchronous teaching, content is delivered during scheduled class time, recorded, and posted afterward. Class time may also include active learning (e.g., breakout groups via web conference, free

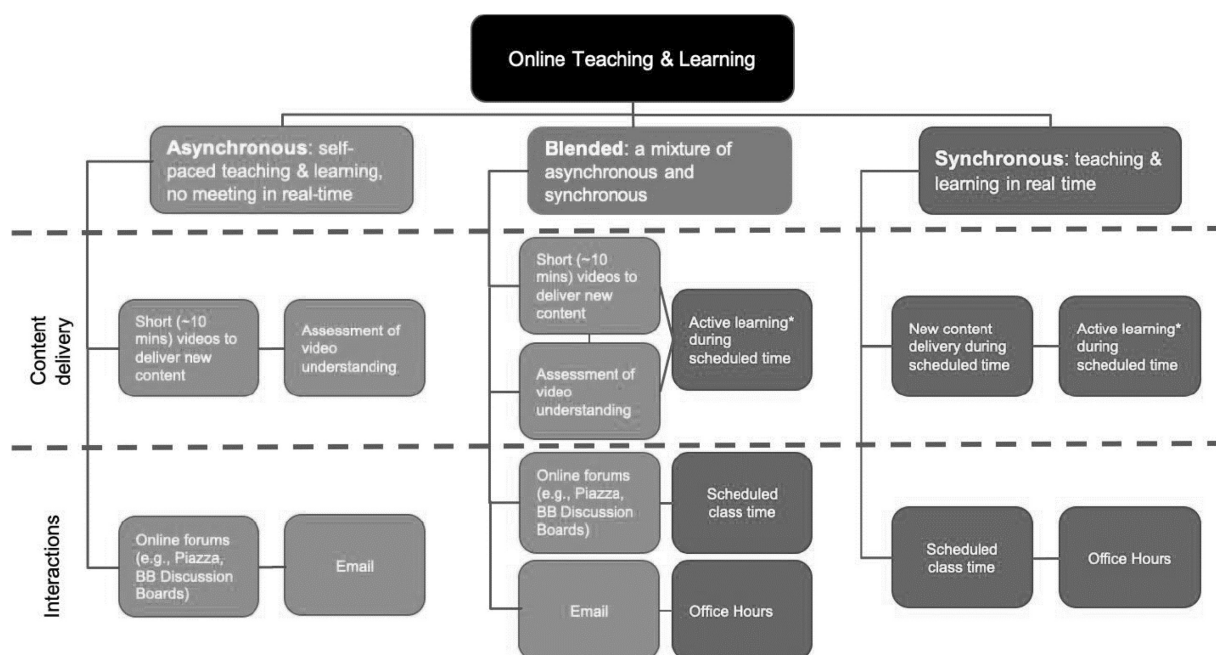
online polling, real-time collaboration by Google or Microsoft 365), team activities, as well as Q&A. Instructor-student and student-student interactions occur naturally during class, reinforced by online forums, online office hours, instant messaging, and email.

Whenever possible, we recommend a blended approach to online teaching, wherein instructors offer both the flexibility of asynchronous content with the engagement of a synchronous class. In this model, content delivery is asynchronous using short videos and follow-up assessments. Additionally, portions of the scheduled class time are diverted from content delivery and used for complementary synchronous interaction, active learning, and in-class activities. Instructor-student and student-student interactions occur naturally during the synchronous meetings, reinforced by online forums,

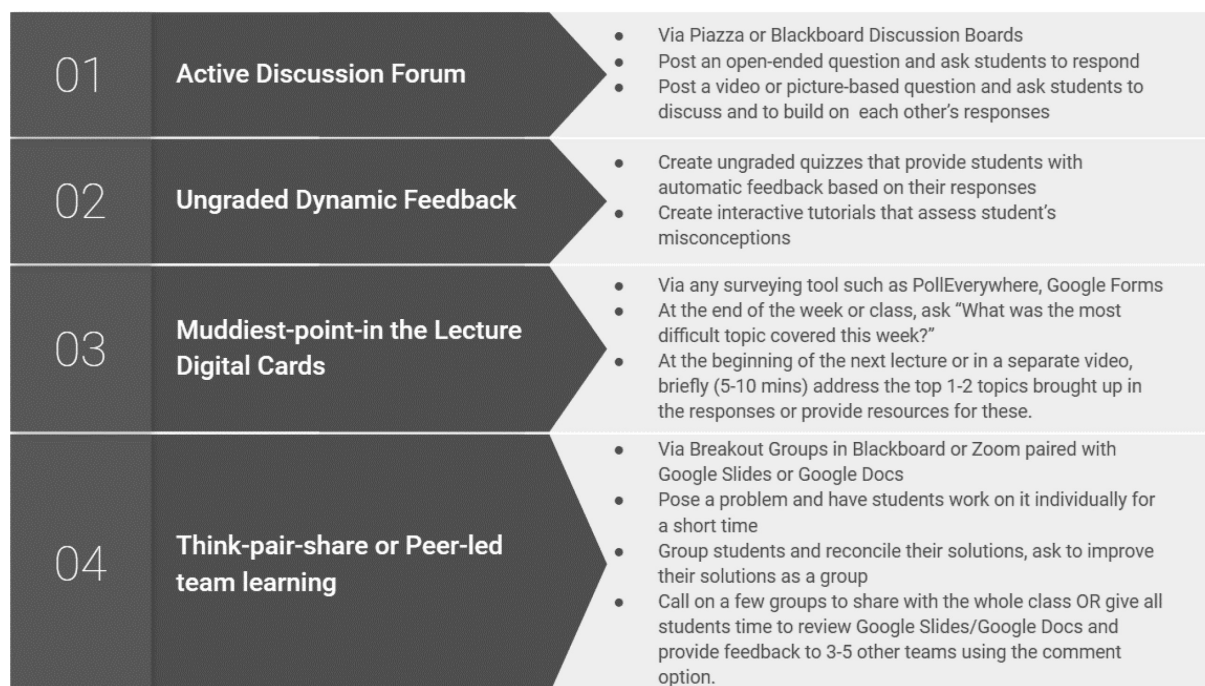
online office hours, instant messaging, and email. There are many aspects to blended course design, but this method has been shown to be effective in learning and engagement with students [8]. Moreover, a recent study reported successful implementation of these techniques during the pandemic to enhance student engagement [9]. This approach also accommodates students who cannot meet during a scheduled time as well as students who may experience internet access issues. Instructors should also utilize active learning strategies to diversify their lectures and encourage interactions. The strategies provided in Fig. 2 are inspired by “traditional” methods of active learning that can also work for online teaching [10, 11]. These strategies are meant to serve as a starting point for integrating active learning into an online classroom.

**Table 1.** Educational delivery modalities for online teaching and learning

Educational Delivery Style	Definition
Asynchronous	An online class where the lecture content is pre-recorded in short, topic-oriented videos. These videos are posted well in advance of any activities requiring this content. An asynchronous mechanism for student Q&A is supported, with questions answered in a timely manner. A recommended best practice is a short assessment after each video.
Synchronous	An online class that meets live during a pre-arranged time. These meetings are recorded and posted for students unable to attend. A synchronous mechanism for student Q&A is supported, with questions answered during class.
Blended	An online class featuring the best of both the asynchronous and synchronous approaches. The asynchronous recordings focus on the lecture content which, following best practices, are short and posted in advance; all students are encouraged to view these recordings. The synchronous meetings follow the release of the asynchronous recordings and are meant to be complementary, providing an opportunity for active learning, student engagement, and a sense of belonging. Blended classes cannot require attendance at synchronous meetings; attendance must be at the student’s discretion.



**Fig. 1.** Educational delivery modalities for online teaching and learning with recommendations for content delivery and interactions. Active learning strategies are suggested in the text.



**Fig. 2.** Active learning strategies for online teaching and learning.

### 3.2 Lab Classes

Lab classes can be difficult to conduct remotely, as they often require special equipment, software, or consumables. Further, each department may have special considerations to balance related to materials and content. For these reasons, a variety of potential content delivery options are identified, as outlined in Table 2. Recently published studies on bioengineering lab classes during the pandemic have indicated that learning outcomes can be met with these techniques [12] and that students gen-

erally find at least some of these content delivery techniques favorable [13]. Notably, in the event that a lab (or even traditional class) must be held in-person and on campus, instructors, departments, and colleges should consider the need for personal protective equipment, air circulation, cleaning of the spaces/furniture/equipment, floor guides for social distancing, and even physical barriers. The safety of all should be equitable and paramount.

In addition to the content delivery options outlined in Table 2, the following suggestions are also

**Table 2.** Options and descriptions for online teaching and learning in lab classes

Lab Class Option	Description
On-Campus with Social Distancing	Students attend laboratory sessions on campus as usual. They work either individually or in teams while maintaining social distancing. Students may rotate attending with other team members, with data being provided to non-attending team members. Cameras may be installed at stations for the lab instructor to interact with students and benchtops. Lab spaces may be expanded increasing the number of stations or multiple rooms that may be used.
On-Campus with Remote Students	Some students attend laboratory sessions on campus, while others participate remotely through video. Remote students may work directly with groups or view recordings provided by the lab instructor, but in either case, they are viewing the physical performance of the experiments. Students may rotate attending with other team members.
Remote Simulation of Physical Labs	Labs that would traditionally take place on campus are done virtually, with students receiving some combination of videos, animations, datasets, and simulations representative of lab content. Students then analyze their data and submit reports as they normally would. Datasets can be provided by a TA or instructor or from websites like openneuro or proteomicsdb.
Remote Software Based Labs	Labs that are traditionally computer-based can be adapted to be completely remote. Students may work individually or in teams, accessing necessary software on their personal devices, through remote login to computers on campus, or by visiting computer labs on campus (depending on availability).
Labs using Take-Home Equipment	Students perform their experiments at home with kits they purchase or rent. They demonstrate their work to the lab instructor through pictures or video and submit reports as they normally would. Examples include AnalogDiscovery 2 or Arduino kits for instrumentation.

provided. (1) Provide cameras and recording equipment at lab stations to permit recording. This allows instructors to record sessions for students who cannot attend and possibly offers a live remote attendance option. (2) Provide computers with remote login. Students may not have access to the software necessary to complete experiments or may not have devices that meet requirements. This option can be added to many existing computer stations on campus. (3) Reduce lab session time and encourage work outside of the lab. Reducing the length of sessions allows for more flexibility for scheduling and time for cleaning. Consider emphasis on pre-lab exercises to speed up procedures. (4) Add additional lab sessions. Adding more sessions allows for more social distancing in lab spaces and provides more flexibility to students. This may require more personnel to support. (5) Reduce shared items and surfaces. Items used by multiple students or instructors should be removed or reduced from lab spaces to lower the chance of virus transmission. Examples include excess seating and sparsely used equipment.

### 3.3 Assessments

Many of the assessment tools used when teaching in-person (e.g., live, high-stakes exams) do not translate well to online teaching and learning. For example, administering an in-person exam online with a rigid schedule and online proctoring may negatively and unfairly impact students due to unforeseen issues that arise through no fault of their own. Instead, we recommend a reexamination of the course objectives and learning goals, and an

exploration of ways to best measure the achievement of these objectives and goals in an online setting; several considerations and examples are provided in Table 3. For further reading, a summary and comparison of common online assessment techniques is provided by Stevie Rocco [14]. While many instructors are accustomed to paper-based grading, online grading can be semiautomated using LMS and even synchronized back to LMS using other tools like Gradescope. Moreover, it has been shown that online learning and assessment can be a positive experience for students and instructors and even lead to new innovations despite negative predispositions [15]. Course outcomes and expectations should be made clear to students, and instructors should help students stay on track with smaller, more frequent assessments on a predictable schedule as outlined with a learner-centered syllabus [16]. The revised approach to assessments can alleviate some of the stressors experienced by students and provides several options for instructors to adopt and modify as necessary.

### 3.4 Community

With the online shift in education, a sense of community among students is both more difficult and important to foster than before. Both instructor-student and student-student interactions are key to creating a sense of community, which, in turn, boost student motivation [17]. Instructors should encourage such interactions in as many forms as possible, including frequent feedback on instructor performance [18] and

**Table 3.** Considerations, examples, and explanations for student learning assessment during online teaching and learning

Consideration	Explanation and Opportunities
Frequency and intensity	Rather than infrequent (and high-stakes) assessments, evaluate student learning regularly with more frequent, less intensive alternatives. This can enhance student engagement and motivation, circumvent transient issues (emergencies or internet access) as well as decrease grading demand on instructors especially if smaller assessments can be auto-graded (e.g., Gradescope). Also consider small multiple-choice quizzes through learning management systems, short written reflections, video logs, projects, and peer evaluations (e.g., CATME). As much as possible, follow a predictable schedule to minimize missed deadlines.
Flexibility	Online learning can be extraordinarily challenging, which calls for compassion and flexibility from the instructor. Consider flexible due dates, multiple allowed submission, regrades or revisions, extra-credit incentives, and dropping lowest scores.
Rubric	Develop, share (prior to submission), and use grading rubrics. Rubrics save time during grading, ensure transparency and fairness.
Academic Honesty	Instructors cannot prevent all academic misconduct, especially when students may have access to online search engines, tutoring sites, and their own course materials at all times. Instead, ensure an equitable challenge by making exams open book and allowing internet search. Often, questions can be reworded to require insight or interpretation, which cannot be easily searched. Further, instructors can minimize blatant misconduct by taking advantage of learning management systems features such as question pools, random question order, randomized multiple-choice answers, no backtracking, and time limits.
Synchronous vs. asynchronous	With students being off-campus, there is an increased likelihood of students being in different time zones, unable to find a quiet place to work, or experiencing unreliable internet access. Consider adopting only asynchronous assessments to ensure equity, and use synchronous and low-stakes assessments as a learning tool instead.

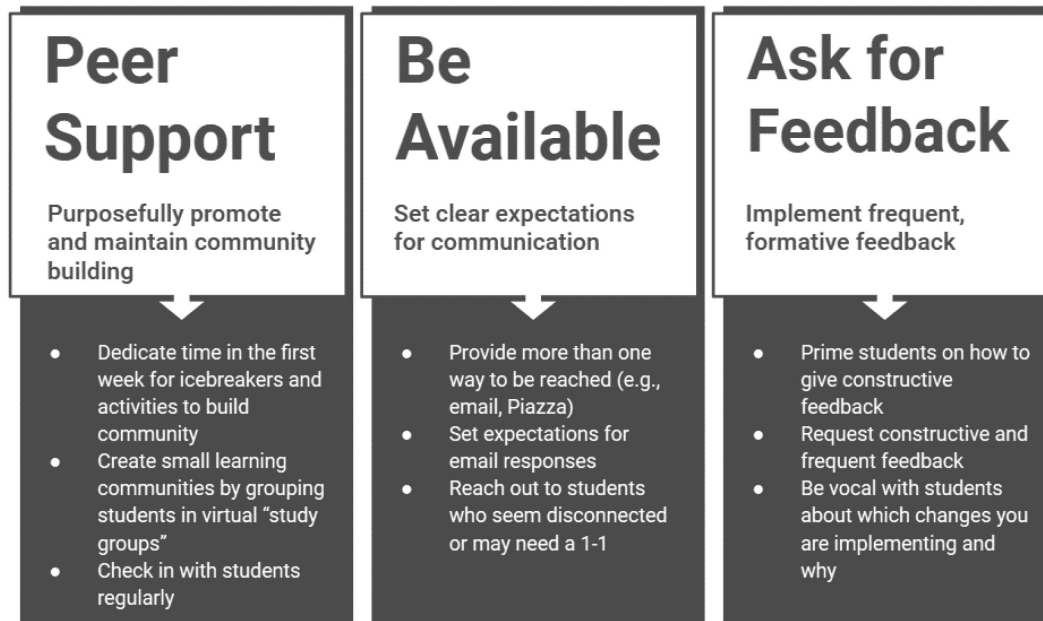


Fig. 3. Methods to foster student community during online teaching and learning.

classroom chat applications which have been shown to enhance engagement and activity [19]. Also, consider asking each student to create a short video or multimedia slide introducing themselves, and share these videos/slides at the start of class (with student permission); instructors should provide a similar introductory video/slide. Another strategy is to “team-up” your students on a given assignment, or perhaps for the entire semester. The latter helps students become comfortable discussing in small groups as they build trust with one another over time. Semester-long teams also provide students with another support network. Fig. 3 summarizes some key strategies to foster a student community. Moreover, tools to facilitate a sense of community may be borrowed from the lecture classes section (3.1). In fact, recent publications during the pandemic have suggested these as well as other strategies to enhance student engagement and community, including web conferencing, daily questions, dynamic polling, and inclusion activities [20–22]. Overall, fostering a sense of community is critical to students and these strategies assist in connecting students to their peers and instructors.

#### 4. Continuing Challenges

While adoption and efficacy of these suggestions has yet to be evaluated, some notable challenges can be predicted. Principally, when transitioning students accustomed to an in-person classroom to online learning, they may feel particularly disengaged [23]. The blended approach to synchronous

and asynchronous content delivery we recommend here can also result in unique challenges. First, asking faculty to change their approaches to content delivery can be a challenge, especially if educational institutions do not have a centralized curriculum or set of standards. Second, a blended approach requires more organization and planning for effective execution. Poor communication and coordination between instructors and students can easily undermine the best pedagogical intentions. Third, instructors employing a blended synchronous and asynchronous approach should be cautious against demanding too much work; despite the potential for enhanced engagement, the course contact hours and learning objectives have not likely changed since the onset of COVID-19.

#### 5. Conclusion

The shift to online education resulting from the COVID-19 pandemic has been swift and challenging for most schools. Here, in the United States, at UIC, students want to be on campus with their peers, they are stressed in new ways than before, and they perceive lower quality of education after shifting online. Instructors needed to rapidly evaluate and develop approaches to deliver content online. While the desire to return to campus is strong for many, it is critical that such a decision be made with the utmost care to protect every individual. Given the unknown epidemiological changes that may occur in the future and the willingness or ability of students and instructors to

return to campus, it is prudent to prepare for online teaching at least in some part in Fall 2020 or beyond. Many approaches, considerations, best practices, and tools for delivering content online for most class types are presented. These recommendations are generated based on survey data and with input from all departments within the College of Engineering at the UIC. It is our aim that the recommendations presented serve as a reference and guide for others in their preparation for online engineering education in response to COVID-19.

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6.2 *Conflicts of interest/Competing interests*: None.

6.3 *Ethics approval*: This Teaching Tips report is classified as non-research related Quality Assurance/Quality Improvement according to institutional policy at the University of Illinois at Chicago. As such UIC IRB approval was not required.

6.4 *Consent to publish*: All listed authors have agreed to the publication of this report.

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