ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022

Paper ID #36689

# Virtual adaptation of introductory materials engineering: a partially asynchronous approach to engage a large class


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**Abstract**
With large enrollments (about 200-350) of primarily non-majors, engaging students in the required introductory materials science and engineering course at our university has been a longstanding challenge. In moving to the virtual format in the fall of 2020, we significantly adapted several aspects of the course, many of which have continued to the hybrid format in future semesters, with good results. The primary content was provided through asynchronous videos; this format allowed us to break content into digestible pieces. In particular, multiple mini-lectures and example videos were pre-recorded for each week, with a total viewing time per week somewhat less than the typical total class time. To provide real-time, structured interaction, one live virtual class session per week was held, centered on previously submitted student questions. Smaller teaching-assistant-led recitation sections also met live (virtually or in person), during which "clicker" questions were asked through TopHat. Assignments were also updated to take advantage of the virtual format. Multiple small assignments with lower stakes were due throughout the week: a reading/lecture quiz, a survey to submit questions, and a shortened homework assignment. Finally, we changed some content near the end of the course to allow students to connect the course to their own career aspirations, which we expect can aid in long-term retention. Specifically, students chose among several possible topics to cover in the final weeks, covered via typical pre-recorded lectures and reading, and also guest lectures. They wrote an abstract-length reflection on how they could use what they learned in this course later in their careers. Overall, students remained engaged with the course throughout the semester and provided favorable comments and evaluations of the course, including higher numerical evaluations of the course than in prior semesters.

## Introduction

Introduction to Engineering Materials or Introduction to Materials Science courses are often the only experience students in other engineering disciplines have with Materials Science and Engineering Departments, thus, these courses include broad content about common types of engineering materials and their material properties. Specifically, the Introduction to Engineering Materials course at the Ohio State University is taught each semester as a single large section with about 350 students in the autumn and 200 students in the spring. Recently, two faculty members (Brown and Locke in the autumn semesters) serve as co-instructors for the main course section, and teaching assistants are assigned to lead several smaller recitation sections. It is the main service course taught in the department, in which approximately 90% of the students are not Materials Science and Engineering (MSE) majors. Instead, the students are primarily mechanical or biomedical engineering majors. Engaging a large class of mostly non-majors is a challenging task, particularly when balancing the goal of properly preparing the MSE pre-majors for their future MSE content.

As with the rest of the academic world, we were faced with the reality of moving this course online in autumn 2020 (AU20) due to the COVID-19 pandemic. With one summer to plan, we were able to restructure the course to lean into the advantages of online instruction, using best practices from the literature as a guide [1], [2].

Here, we first describe the class format, which included short asynchronous videos for most of the core content along with live virtual classes for pre-submitted questions. We then discuss the results in terms of student engagement and learning. Finally, we discuss lessons learned and how we have continued to update this format in future semesters with more ability to meet in-person.

**Class format**

Our overarching strategy in moving to the virtual format was to capitalize on the advantages of the online format, when possible, especially to ensure student interaction and engagement. For instance, instead of a single, 55 minute in-person lecture, online videos can easily be broken into shorter, digestible portions. The pre-recorded lectures were typically 10-30 minutes long; the videos were split at natural breaks in the topics covered that week. Separate videos were made for new content and for examples of applying the content, as exemplified in the screenshots of these two types of videos in Figure 1 (one teaching the students about crystallographic plans and how they named and the other given further examples of different planes). This also allowed the teaching faculty to split the workload of planning and recording the lectures for the course, with one instructor primarily presenting the content lectures and the other primarily presenting the examples.

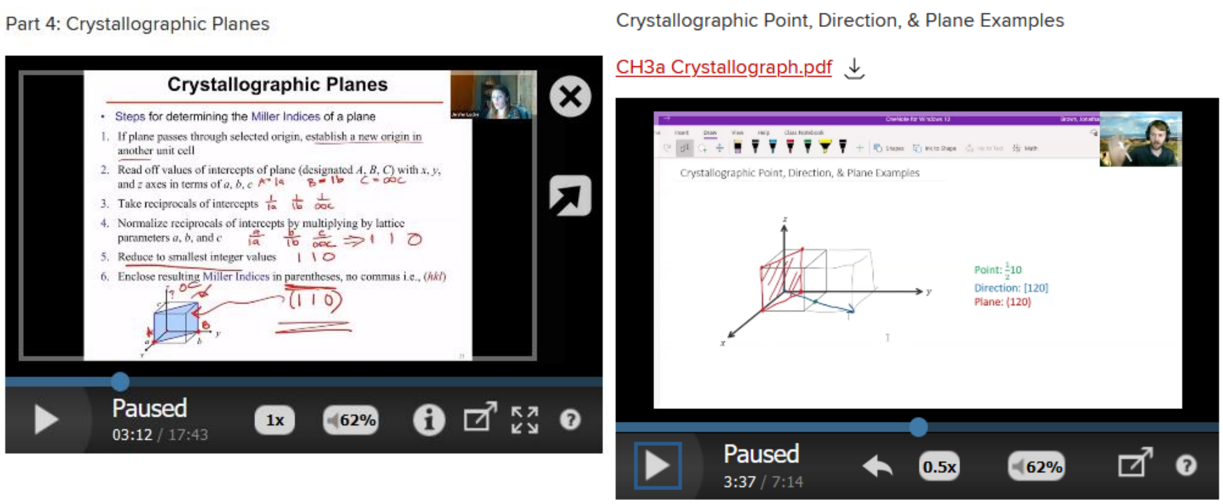


*Figure 1: Example screenshot of a video presenting new content (left) and of a video presenting an example of applying content (right).*

This format was easily standardized so that each week would correspond with a single topic (a chapter from the book), even though the length of an individual chapter may vary slightly from week to week. The total length of the videos each week was typically somewhat less than what the students would have in a traditional lecture (55 minutes times 3 times per week), with some weeks longer for more complex topics and some weeks shorter for more straightforward ones. The students could easily stay on pace with the course as they had a consistent week-to-week schedule with fixed deadlines for the various assignments. The weekly content was organized consistently using Modules in the Canvas Learning Management System as shown in Figure 2.

Assignments were also split into smaller parts, and with smaller stakes, compared to the previous typical format of homework that was due after the material was covered in lecture. Specifically, after the pre-recorded lectures (and reading) the students took a low-states, untimed quiz on the material, with immediate feedback and multiple attempts at each question. After that, they filled out a survey to detail largest areas of confusion ("muddy point") and attended the synchronous meetings for the week to cover once again these areas (detailed below). Finally, at the end of the week, a relatively more complex (as compared to the reading quiz) calculation-based homework assignment was due. The questions on the homework also had immediate feedback, and students had infinite attempts at each question. This both alleviated some frustration with the automatic grading of online homework systems, and allowed the students to experiment, try things, and ask questions without fear of losing points.

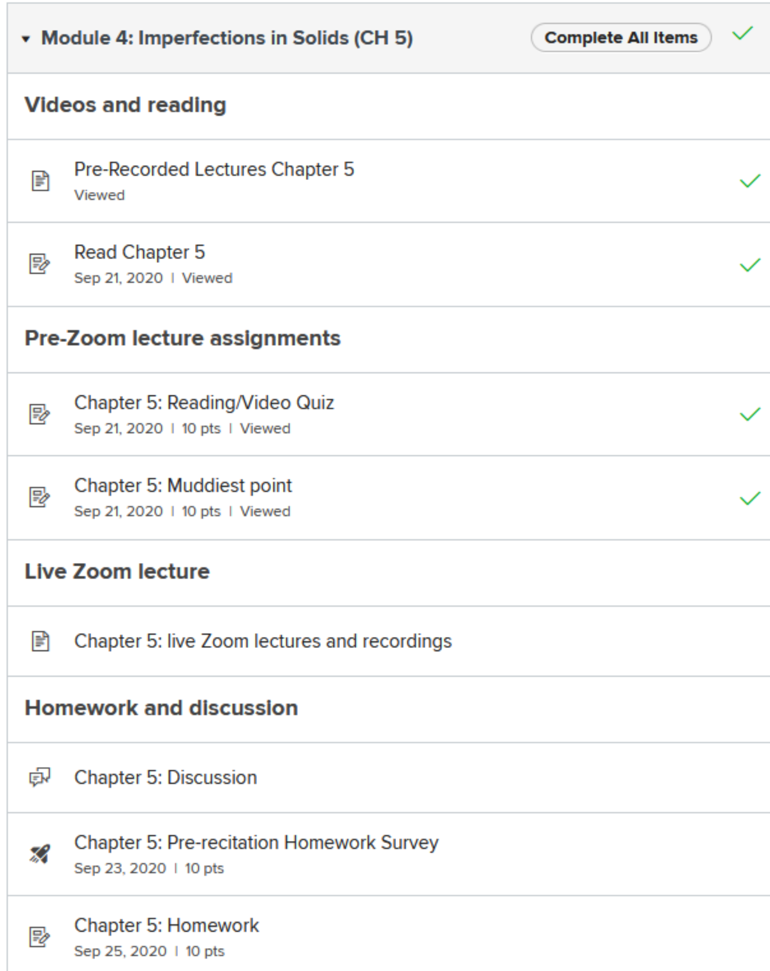


*Figure 2: Screenshot of a weekly module for the course*

Two synchronous meetings during the week, one with the whole class and one in recitation sections each lead by a teaching assistant (TA), were an opportunity to overcome the main disadvantage of the pre-recorded lectures, that is, the lack of student interactivity. We hoped to add interactions both with the instructor and between students. In the whole class instructor-led synchronous meeting, we discussed student submitted "muddy points" to focus on student engagement with the instructor, and the class met in smaller groups for the TA-led recitation that facilitated student-student interactions. In an all-virtual format, the synchronous meetings were accomplished using Zoom. In the hybrid mode, the larger class could be in-person or on Zoom depending on the current circumstances, and the smaller recitation sections were generally held in person, with an online recitation option also provided.

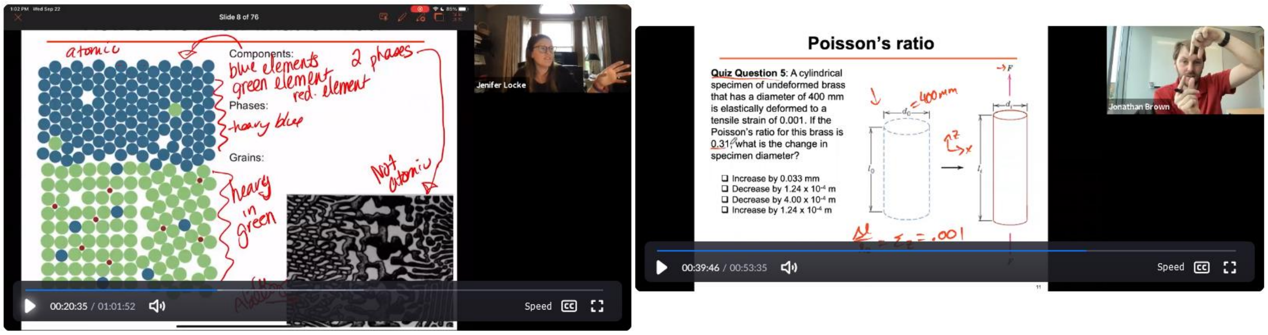

*Figure 3: Two screenshots of typical "muddiest point" class discussions.*

Specifically, each week students were required to submit a brief survey detailing their "muddiest point" on the material covered in the pre-recorded lectures (or assigned reading from the textbook). That is, "what, if anything, did you have the most trouble understanding this week?" This was purely for participation credit, and the students were told that "nothing" was a perfectly acceptable answer. Using these surveys, which were summarized by a TA with a count of topics with some examples of student questions, the instructors would prepare a lecture to answer these questions and review the (student-identified) most confusing topics. These lectures were presented in a synchronous online meeting, which was changed to in-person in spring semester 2022 (SP22), with prepared slides (see screenshots in Figure 3). This allowed students the opportunity to ask follow-up questions and interact with the instructors.

The TA-led recitations were also run as synchronous meetings, held online or in person depending on the current situation. In these meetings, the focus was getting students to engage with one another mediated by a TA. The TA would use TopHat, an online active-learning platform that allows instructors to poll students and view real-time results, to ask conceptual and calculation questions, students would vote on the answers they believed were correct, and the TA would lead a discussion of the topic. A library of questions was built into TopHat that each TA could choose from during the recitation. This approach allowed the recitation leader the flexibility to focus on topic areas that students were struggling with and to move on from topics that students already understood based on real-time feedback from TopHat. Students were also able to work in small groups through Zoom breakout rooms and, as pandemic restrictions were lifted, in person. Recitations were also used as another forum for students to ask questions, but in a more informal setting than the whole class meetings; the class size was much smaller (30-60 students) and led by a graduate student instead of a professor.

As mentioned above, the student enrollment consists mostly of non-materials majors, who may not engage with or retain the content if they do not recognize the connection to their primary discipline. Additionally, students have diverse goals, interests, and backgrounds, and they may be in their first year or may be taking this course in the final year or two of their college careers, despite it being an introductory level. Motivated by this, we have tailored the final few weeks of the class, as well as the final, to meet the needs of this broad audience.

In particular, the last two weekly modules were made in a different, more open-ended format. For the second to last week, a "choose your own adventure" module was created where the students individually choose chapters to study that most relevant to their major. This is possible because many chapters in the second half of the book utilized [3] are self-contained excursions into different material properties (corrosion, electrical, magnetic, thermal, etc.) of more or less interest in different sub-disciplinary areas. The following week, a slate of guest lectures recorded by other faculty members in the department or external industrial experts was provided. Students again were able to choose what part of that content most interested them, and they watched several of those lectures and wrote a brief reflection. The goal of both these weeks is to broaden the course content beyond what we have time to cover in detail in a typical semester-long course while remaining relevant to the students' individual interests.

To go along with this format for the last few weeks, the "final" for the course was changed to a short (300 word) reflection paper. In this final paper, the students explain how they believe they will use the learnings in this course in their future career. This format was chosen for two reasons: first, education research has found that student reflection can help retention [2], and second, this allows students to develop personal take-aways that demonstrate their individual progress (it is otherwise difficult to assess the last two weeks of content given that each student has their own content choices). The content before the last two weeks is tested in the usual academic manner with mid-term exams.

**Results**

Overall, students enjoyed the class and remained relatively well engaged throughout the semester. Attendance at the (optional) recitation and muddy points lectures was typically a third to half of the students, in line with attendance in the traditional lecture format, and the pre-recorded lectures were watched by the majority of the class throughout the semester.

The end-of-course student evaluations provide insight into the student experience. Multiple positive comments mentioned the consistency and layout of the course, as well as the videos being broken down into small pieces. (However, a minority of students mentioned preferring hour-long live lectures to the pre-recorded format.) For example, below are two student comments from autumn semester 2020; similar comments were left in spring and autumn semesters 2021):

> It is structured very well compared to my other online classes. I like that the course is laid out in modules with clear instructions each week.
>
> Having the modules system made it so that there was never a question on what I needed to do, and having the shorter videos make it easier to focus while watching the lectures sitting in my dorm.

Furthermore, in a survey at the end of the autumn 2020 semester, we asked "what suggestions do you have for the instructors next semester?" Of the 215 responses received, the top three most popular were: no changes (60 students), synchronous lectures instead of pre-recorded (25 students), and shorter/more concise lecture videos (24 students). Other comments had much less consensus; the 4$^{th}$ most popular response (from 13 students) was about the unpopular broken-up schedule we used in the beginning of that semester (see below), which had already been changed.

In addition to open-ended comments, end-of-course evaluations asked students to rate various aspects of the course/teaching using a Likert scale with 5 options ranging from "Excellent" to "Poor", which is then converted to numerical averages (on a range from 5-1) before being returned to instructors. On the summary question, "Overall, I would rate this instructor as...", students rated the instructors as an average of 4.17/5 with a standard deviation of 0.17 in the four semesters (AU20, SP21, AU21, SP22) this course has been taught in the way described above. Before this change, recent ratings (from several different faculty instructors, averaged by semester from autumn 2013 through spring 2020) had an average of 3.54/5 with a standard deviation of 0.35, which reflects typical low ratings for a class of this type: a large, technical undergraduate course consisting mostly of non-majors who take it as a degree requirement.

In addition to formal student evaluations, students were also surveyed to give anonymous feedback to their recitation instructors and the format of the recitation. The feedback received was generally positive from students who regularly attended recitation. For example, in autumn 2021 and spring 2022, students were asked "Do you feel that your learning in [this course] was enhanced by recitation in general? Why or why not?" Typical positive responses included:

> Yes, I believe having a recitation for [this course] is extremely beneficial in solidifying my knowledge regarding the subject. I felt like the TopHat questions were fantastic to look back at before the exam and use as a study tool

> Yes. I think that recitation was really helpful because it helped really drive home the concepts. TopHat was really helpful as well because they were more concept/thinking questions rather than calculations. It was also really nice because I was able to better understand concepts because I heard the same concept just explained in a different way.

Students who responded "no" to the above question (17 of 107 student responses in AU21, and 6 of 79 in SP22) typically did not like using TopHat for recitation, as they often felt the questions did not go into enough depth to be helpful.

Test and other assignment scores provide insight into student learning of concepts. While it is difficult to make a close comparison across semesters as the assessments were not the same, we did not notice significant changes to student grades as we moved to the new format. In the new format, we also implemented a conceptual pre- and post-quiz (the same quiz, up to some cosmetic changes, taken at the beginning and end of the course) based on the materials concept inventory by Krause et al. [4]–[6]. Data from these quizzes is shown in Figure 4; student gains (the difference in the average score between pre- and post-quizzes were 26% in AU20, 28% in SP21, and 27% in AU21, and 26% in SP22) were between the gains found using the materials concept inventory with and without active learning [4], [7], but a direct comparison is not possible, as some of the questions used were cut or modified to match the different content covered. Instead, this data suggests the above course design is at least as effective as traditional instruction, and we also use this data semester-to-semester to refine our teaching of topics in which students continue to struggle. Additionally, pre-testing helps students learn [1], [8], and pre/post testing can show students their progress in the subject matter.

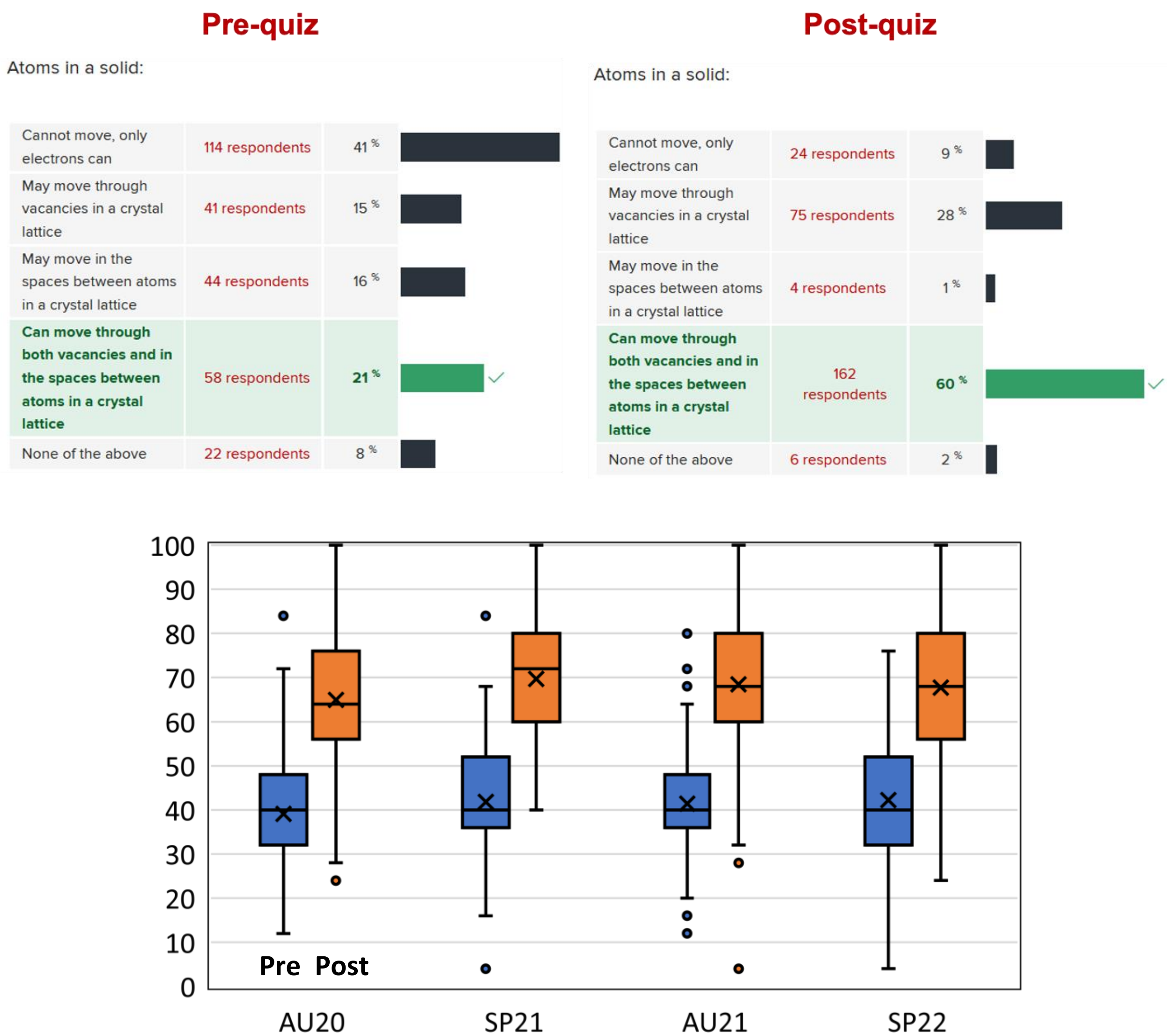


*Figure 4: Top: Distribution of answers on an example question on the pre-quiz (left) and post-quiz (right). Bottom: Boxplot of pre-quiz (blue) and post-quiz (orange) percentage scores on the conceptual quiz for the four semesters it has been given.*

## Lessons Learned

The adjusted format of this course was popular with students as compared with a typical lecture course, and it appears to lead to good student engagement and learning. Given good results and comments when all courses where online in Autumn 2020, this new format has been retained into the following three semesters, even as classes began being held in person. Specifically, starting in spring semester 2022, the class was not an online class, but still maintained a similar format of video lectures followed by synchronous meetings, with the synchronous meetings now moved to being in-person (recitations were also held in-person). However, there have been a few adjustments made along the way based on student feedback to refine the format.

In particular, initially the students were broken into groups to allow for smaller muddy-points lectures (1/3 of the class was assigned to each group which met for muddy points lecture on a different day each week). The intent was to give the students more individualized attention and have more time for questions. However, this also necessitated different due dates and schedules for the three groups, which the students found confusing. In mid-semester surveys, students voted 2-to-1 to simplify the system and meet as a whole class in a single muddy-points lecture each week.

Another change was to assignment due dates. Initially, they were set to the end of the standard workday (5pm), but students also found that confusing and frustrating, as they do not always follow standard work hours and most due dates for their other (online) classes were at midnight by default. We followed suit with the other classes and set due dates to midnight after learning of this issue in the mid-semester feedback.

In summary, because of the introductory nature of the Introduction to Materials course, large fraction of non-majors, and large class sizes, it can be challenging to engage students and ensure they make connections between the course content and their future coursework and careers. By moving to a virtual format, starting in autumn semester of 2020, we have adapted the course format in a way which seems to effectively promote student engagement. We hope this also helps learning and long-term retention. The new course features were generally continued in future semesters in the hybrid virtual/in-person format, and we continue to refine the course further each semester. Additionally, the fully online version of this course could be utilized in the future as a model to create a distance introductory course.

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