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JUNE 22 - 26, 2020 #ASEEVC
Paper ID #29340

Creating and Facilitating Engaging, Rigorous Fully-Online Technical Courses (or just Online Content for Face-to-Face Courses) - an MEB Example

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Abstract

This paper addresses some common assumptions and concerns about, benefits of, and approaches to offering a rigorous technical course online. A systematic approach to convert each part of a typically face-to-face (F2F) course to an online equivalent or replacement is presented. Course elements such as cleverly designed discussion prompts, student-recorded problem explanations, and online assessments designed as described here may be used to increase student engagement, motivation, and content retention in any course.

A fully-online Material and Energy Balances (MEB) course was offered at the Colorado School of Mines as the first online course offered from this institution's Chemical and Biological Engineering department. With the help of the school's teaching and learning center, the course was fully designed and built online before day 1 of its inaugural 8-week summer offering and was continuously facilitated by the instructor throughout the course. Of the 12 students who attempted the course, all of whom had earned a D, F or W in MEB at least once before, 10 passed with a C- or higher, one with a D, and one did not pass. This pass rate, along with quiz and exam averages and overall course GPA, were not statistically different than those for both a 15-week normal semester F2F and a 6-week summer F2F offering by the same instructor. Student evaluations and comments for the online course were strongly positive, even moreso than for F2F offerings in some ways.

Moreover, student engagement, which may be *assumed* difficult to garner in online courses and is *vital* for success in Material and Energy Balances, was strikingly rich and fruitful in this online course. Methods used to get and keep students engaged in an online course are presented following motivations for offering core courses in summer and for offering them in an online format if possible, along with evidence of the success of the Online MEB course offering. Online tools and course elements presented here can also be used to enhance engagement in F2F courses and/or to create a hybrid (part F2F and part online) course.

Background

Online MEB courses have been offered at other institutions before. For example, the author reviewed an online MEB course at another well-known university in 2014 when our institution was evaluating that course for potential transfer credit. We were initially skeptical of online courses in general – concerned about how the integrity of the exam taking process could be controlled, how rigorous the assessments could be in an online course, how students could really learn material like that online, etc. After speaking with the facilitating professor of the course, we concluded that if a student passed the course, they would be prepared for our curriculum and we accepted the course for transfer credit. Exams were similar in content and format to ours and were mailed to the professor at the university for grading after students took them on paper at a testing center with proctors. Students were ID'd before taking the exams and were watched during the exams. The content, assessments, grading, etc. were all comparable to our course. We were excited to find a possible path for our students to stay or get on track over the summer with this course, and we told the professor so. He then said they were not going to offer the course anymore after that year. Why? In large part because the student success rate was so low that it wasn't worth the time investment, either for the professor or the students. The reason for this, he explained, was that students would sign up and then not bother to do the work and finish the course. They had to be highly self-motivated and self-disciplined to work through the material on their own… another common concern about online courses. That course was not offered online at that institution again after the 2014 offering mentioned above (at least through the time of writing this paper).

The landscape of higher education is changing, however. A quick internet search now reveals a plethora of online undergraduate and graduate course and even degree offerings from a wide array of institutions (community colleges, small and large 4-year colleges and universities, ivy league schools, international technical universities, etc.). Undergraduate science and engineering courses and degrees are right up there with liberal arts programs, MBA programs, health administration, etc. among the online offerings. At the time of writing this paper, US News and World Report indicated 28 schools offering 100% online Bachelor's degrees with "engineering" in the major category, and 76 schools with 100% online graduate engineering degrees. [1] Lab courses are offered online, for example with a box of chemicals, analysis equipment, etc. arriving to the participant through the mail. There are variations in course cost, duration, synchronicity, assessment types, and extent of instructor involvement during the course. An exhaustive review of these offerings will not be provided here but suffice it to say, online courses, certificates, degrees, etc. are here and are growing rapidly in number and importance in higher education. Presuming a given field or course is impossible to offer online is a self-limiting mistake that will leave an instructor or program or institution behind relative to their competitors.

Between the first and final drafts of this paper, the coronavirus pandemic hit and much of the world quickly started moving teaching and learning online, at least partially and at least temporarily. It remains to be seen how this will affect teaching and learning in K-12 and higher education in the long run, but one possible outcome is that it will serve to accelerate the pace of the transition to more and more online learning opportunities from this point forward. Unfortunately, this crisis means many educators are making this transition very quickly, which may lead to less than ideal online learning experiences. It is important to recognize that the quality of online courses, just like the quality amongst any set of courses, can vary dramatically. Online learning as a whole should not be judged solely by whatever results from much of the world quickly transitioning traditionally F2F courses to a remote learning environment. At Mines, our teaching and learning center has made a clear distinction during this time between "remote learning", the mode to which we have transitioned our courses during this crisis, and "online courses", which are designed, developed, and facilitated following a rigorous process to be as engaging and successful as possible. This process is outlined in detail in this paper.

Many resources are available that help make creating online courses or content relatively easy and even fun. WileyPLUS [2] and McGraw-Hill Connect [3] are two examples of publisher resources that offer digital content including searchable e-texts, videos, adaptive reading question sets, calculation problems, concept questions, and more. Pearson and other publishers have similar products. Learncheme.com [4] and the AIChE Concept Warehouse [5] also offer great digital resources specifically for Chemical Engineering courses. Learncheme.com has >1650 screencasts, >1900 conceptests, >200 interactive simulations, >50 interactive self-study modules, and >20 step-by-step interactive simulations uncovering content from most or all Chemical Engineering core courses.[4] The AIChE Concept Warehouse has >3000 available concept questions, >1200 faculty accounts, over 1.3 million concept questions answered, and over 30,000 students connected and learning.[5] Even if they have never created an online course, many instructors have used resources like these to supplement or help flip traditional F2F courses. Transitioning from this type of teaching to offering a course or a program online is not as big of a hurdle as one might imagine.

One advantage of creating or using digital content like this is "freeing up class time", since at least some of the content is delivered out of class rather than in class. Done well, this can provide additional advantages for the students as it allows them to explore the content in a variety of ways, at their own pace, and at a time and place that may be more amenable to their learning than in a classroom full of other students at a set time. These advantages address multiple levels of diversity amongst learners.

The newly found "class time" gained by delivering content outside of class rather than in the classroom is then often used in F2F courses for activities that help students learn and retain information better. Some of these in-class activities could potentially be just as well done by a student on their own; working on a calculation problem, reading and interpreting a passage, studying and interpreting a figure or graph, reflecting and writing a minute paper, to name a few. Other activities benefit significantly from the interactions between students or students and learning facilitators (instructors, TA's, peer educators); think-pair-share questions, clicker questions followed up with instructor feedback based on student answers, working in groups on constructive and interactive tasks, etc. It may be clear how individual activities that traditionally take class time can be replaced with online course activities. It is this author's contention that with careful design and planning, even interactive activities traditionally done face-to-face can be done well in an online environment as well.

By designing an online course with *connecting and engaging elements* – Zoom office hours, screencast skeleton notes, "SCORED" (SMART, Connecting, Original, Revisited, Engaging, Diverse) discussion prompts, and frequent synchronous assessments – *and by providing quick and targeted feedback to participants on a regular basis*, instructors can engage students as much or even more in an online course compared to F2F courses. Online elements like these can be used to try to increase engagement in a hybrid or F2F course as well.

This paper first explains why we began offering Summer MEB, shows the outcomes of our Summer F2F and Online MEB offerings, and compares these with our traditional Spring F2F MEB course. This provides evidence relevant for assessing the quality of the online course as well as context for understanding how that evidence was analyzed and interpreted. How the online course was designed to keep the students engaged and learning deeply despite their physical distance from one another and how well that worked are then presented.

Our Path Toward Online Offerings

The Colorado School of Mines began offering its first fully-online program, a graduate program in Space Resources, in Spring 2019. Prior to that time, we had offered a few "distance-enabled" courses as part of special programs and continuing education, but only a few and no online courses for resident students. In 2019, 28 course sections for students enrolled at Mines in undergraduate and graduate degree programs were offered online, and we are continuing to expand our online offerings. One particular demand for online courses from our resident students is to offer them over the summer so that students can take classes from home, while working, while traveling abroad, etc. This summer (2020) we plan to offer ~20 new online courses.

Summer MEB – Why, When, Who, How, and Outcomes

The first online offering out of the Chemical and Biological Engineering department was Material and Energy Balances (MEB), which ran in the second summer session of 2019. Summer offerings of MEB are in demand because they offer students an opportunity to get (often back) on track to take Junior year courses in the Fall, either after not passing in the Spring, or because they are advanced first-year students, or they are transferring in from elsewhere. An online offering can be preferred over a F2F offering for students for the reasons of location and schedule flexibility mentioned above. We have offered summer MEB in the traditional F2F mode 5 times before this online offering – 2008 and each summer from 2016 to 2019.

Of the 144 total summer MEB student attempts, 115 were students who had earned a D, F, or W in MEB previously (repeaters), 25 were taking it for the first time, 3 were non-degree students, and 1 was taking the course after completing the degree requirements to increase their major GPA to graduate.

Thus roughly 80% of our overall Summer MEB cohort have been students taking it for the 2nd (or in some cases, 3rd) time. Table 1 shows the enrollments and grade distributions of the 6 summer MEB course offerings by 4 different instructors over 5 different years. Despite the fact that these students are primarily ones who have struggled with the course in the past, ~81% of the 144 attempts led to the students being permitted to move on in the core. In 2008 students were allowed to move on in the core with a D- or better, but in the later years a C- or better was required to move on from MEB to Chemical Engineering Fluid Mechanics (Fluids) and Chemical Engineering Thermodynamics (Thermo) in the Junior Fall semester and also in those two courses to move on to Heat and Mass Transfer and Separations in the Junior Spring semester.

Table 1 – Enrollments and grade distribution in all summer MEB offerings. Shaded entries represent grades that did not allow the students to move on to the Junior year core courses (i.e. to Fluids and Thermo).

Summer MEB							
Offering	**Instructor**	**Enrolled**	**A to C-**	**D**	**FW**	**Passed***	**Mode**
1	A	21	12	5	4	**81%**	F2F
2	A	21	20	1	0	**95%**	F2F
3	B	25	12	8	5	**48%**	F2F
4	C	30	27	2	1	**90%**	F2F
5	D	35	30	3	2	**86%**	F2F
6	A	12	10	1	1	**83%**	Online
Overall		**144**	**111**	**20**	**13**	**91%**	
			Actually moved on:			**81%**	

* Here "passed" means at a sufficient level to move on in the core. A D- or better passed all courses for offering #1; for others a C- or better was required to pass MEB, Fluids, and Thermo.

Online vs. Face-to-Face Comparison

Due to small sample size, the statistical significance of the percentages for each individual course offering, and particularly for the online offering with only 12 students, is low. Student counts in each category are therefore provided to show the comparison of the various summer MEB offerings. Eleven of the 12 students who attempted the online MEB course "technically passed" it (earned a passing grade in the course), 10 at a high enough mark to move on in the Junior core. The one who earned a D+ is currently enrolled for the 3rd time in MEB; i.e. is still pursuing the degree. The one who did not pass self-reported working 60-80 hours per week over the summer at an internship, really enjoying engineering, but simply not having enough time to do the summer course, and ended up continuing at Mines in Fall in another degree option.

Table 2 shows at a finer level of detail how students in a traditional Spring F2F offering performed in the MEB course compared to those in a Summer F2F and the Summer Online offerings by the same instructor.

Table 2 – Enrollment and outcomes for all gradable students completing Spring F2F, Summer F2F, and Summer Online MEB course offerings by the same instructor. Ranges shown for grade averages represent 95% confidence intervals on the true means using Student-T tests to account for sample size.

	Spring F2F	**Summer F2F**	**Summer Online**
Enrollment (-W's)	129	21	12
Earned A to C- grade	103	20	10
Quiz average	76 ± 2	77 ± 5	74 ± 7
Midterm average	76 ± 2	75 ± 4	82 ± 5
Final exam average	70 ± 3	74 ± 6	64 ± 14
Course GPA	2.5	2.5	2.3

The quiz, midterm, and final exam averages are not statistically different from one of these MEB course offerings to the next. The "Course GPA" was calculated for each section based on all gradable students (earning A through F) with plus/minus grading where A = 4, A- = 3.7, B+ = 3.3, etc.

Bottom line: student pass rates and averages on quizzes and exams in the first online MEB offering were comparable to those for F2F offerings in Spring and Summer by the same instructor.

Performance After MEB

Student pass rates and assessment averages within the MEB course provide some metrics of the quality or success of the course. By these metrics alone, Table 2 would suggest cohorts moving on from Summer MEB (F2F or Online) and from Spring MEB should overall perform equally well in the Junior year and beyond. This has not typically been the case in our experience so far, independent of course format. Cohorts moving on after passing Summer MEB have, on average, performed below those moving on after passing Spring MEB. There are three likely reasons for this apparent dichotomy:

1) Summer MEB has had roughly 80% repeat students vs. <5% repeat students in Spring MEB offerings. *Therefore, student success in Summer MEB likely comes in part from the fact that the students had seen that same material before, typically immediately before, the attempt in which they passed. This may not necessarily translate to those same students doing well in the later core courses that are full of new material.*
2) Summer courses are concentrated, immersion type courses, allowing (/requiring) students to focus more on that one course than they can necessarily be expected to focus on a single course within a normal term down the road. *Thus a given student may pass a summer course, but be less successful with courses during a Spring or Fall term when they are most likely taking several courses at a time in a less concentrated way.* Students who have passed MEB in a normal semester-long offering while also taking other courses (i.e. in the Spring) have better demonstrated this particular time management skill.
3) Summer offerings have had lower enrollments than Spring courses, offering students more concentrated attention of the faculty relative to Spring offerings. This is true for the online offering as well, as the online course included as much or even more opportunity for individualized support throughout the course compared to the F2F courses. *This higher level of individualized support during summer offerings might translate to relative success in Summer MEB over what can be expected in larger courses offering less individual attention and/or support after MEB.*

To this last point, the author (/online course facilitator) was concerned during the online MEB course that she was providing too much individualized attention in the first couple of weeks of the course and backed off a bit in week 3 and beyond. In future offerings of the course, support will be scaffolded more intentionally to still support yet also better prepare students for more independent work required in the Junior Fall courses. Also some of the supporting features from the online course, such as SCORED discussions with groups and providing feedback based on students' recorded explanations, are being incorporated into Spring and Fall courses as well.

Even though the Summer MEB students on average underperform in later courses relative to their Spring MEB counterparts, the Junior Fall outcomes still show that this summer opportunity helps *most* students, even those who have struggled before, *stay on track/graduate on time*. Of the 144 student attempts at Summer MEB, 116 passed with high enough grades to take Fluids and Thermo the following Fall. Table 3 shows the numbers of those 116 who enrolled in each Fall core course and their performances in those courses. Some students switched after summer MEB to other degrees at the school, some were non-degree students to begin with, and some enrolled in just one of the two Junior Fall courses - hence the enrollment numbers not matching or equaling 116.

Table 3 – Enrollments and grade distributions in Fluids and Thermo. These numbers are of the total 116 students who passed with high enough grades to move on after 144 attempts at Summer MEB. Recall that to move on in the core to Junior Spring courses, a D- or better was required in 2008 and a C- or better was required for the later offerings, hence the "Moved On in Core" counts being higher than the "A to C-" counts.

	Enrolled	A to C-	D	FW	Moved On in Core
Fluids	106	86	11	9	87 (82%)
Thermo	103	69	23	11	74 (72%)
Fluids & Thermo	102				67 (66%)

Our overall rate of students passing both Fluids and Thermo at sufficient levels to move on in the core from Junior Fall to Junior Spring is higher than 66% (it was 84% for the 2015-2019 timeframe). This is not surprising though, as the 84% number includes our whole student population, most of whom do pass MEB the first time through. It is important to note that most of those students who did not move on in both Junior course tracks (1) from Fluids to Heat and Mass Transfer, and 2) from Thermo to Separations), *at least moved on in one of them*. Also, even students who failed both Junior Fall core courses at least got to see that material a year earlier than they would have had they not taken and passed the Summer MEB course. If they had had to wait until the following Spring to re-take MEB instead, they would not have had this preview of Thermo and Fluids, likely making their first attempts at those courses the following Fall more difficult. *Hence, the Summer MEB offerings helped all continuing CBE students progress toward their degrees*.

Of the 144 summer MEB attempts, 47 students have graduated with CBE degrees as of March 2019: 36 on time, 8 plus 0.5-1 year, and 3 plus more than a year. Another 68 are still working on their CBE degree. Of the remaining 29, 14 switched to other degrees at this school and 15 left the school without a degree or are at least currently not pursuing CBE at Mines.

Summer MEB as a Way to Help Students Find Their Path

Some students end up deciding that Chemical Engineering is not for them after taking this gateway course (perhaps for the 2^{nd} or 3^{rd} time). For those students, having the chance to recognize this *as soon after their first unsuccessful MEB attempt as possible* is vital, as it allows them to consider other options before investing another academic year in Chemical & Biological Engineering. Historically, most students at this institution who have attempted MEB have persisted in CBE even if it took them multiple attempts to pass MEB. Before MEB was offered in the summer, this meant all MEB repeaters graduated at least a year late, unless they found somewhere else to take MEB over the summer and transfer it in. The 29 students shifting away from CBE by the following Spring or earlier out of the 144 Summer MEB attempts, ~20%, is high given our typical persistence rate.

This suggests that having a 2nd shot at MEB before the Junior Fall semester may have helped students who still struggled or did not enjoy the material choose to find a better fit instead of unhappily persisting in CBE. They would have been another year invested in CBE after retaking MEB in Spring instead, and thus might have been too entrenched in the degree to switch to something that would likely ultimately have been better for them. If so, this initially unintended consequence of offering Summer MEB can also be seen as a successful outcome – helping students identify what they enjoy and where they fit while there is time to switch to that path if it is not CBE.

Other Benefits of Online Courses

The path-finding benefit applies to offering Summer MEB, whether online or F2F. Offering MEB, or any course, online rather than or in addition to F2F provides the additional benefits of flexibility for the students, as previously mentioned, plus another potential advantage for the school and the department and yet another for the faculty facilitating the course. For the school and the department, once the course is developed it can potentially cost less to offer the course online each time than to offer a F2F version of the course. Run well, it takes significant time to facilitate even the online course, but over time that per-offering time investment can decrease, possibly to less than that required to run a F2F course. Also, for the faculty member it offers the same kind of flexibility that it affords the students – the opportunity to be wherever in the world running the course and to schedule their time to work on the course around other things. Furthermore, if there is an epidemic or pandemic such as experienced this year with the coronavirus, online courses can continue more safely and relatively unhindered compared to F2F courses.

Designing and Facilitating Good Online Courses

Most of the things to consider when trying to develop a good online course are the same as those for designing good F2F courses: starting with SMART Learning Outcomes; creating a course map; connecting each course element to at least one LO; deciding how to best deliver content; designing activities to allow for practice; providing regular and useful feedback; creating good assessments and rubrics, etc. For an online course, one can begin with these same considerations, then think about what parts are normally done face-to-face and figure out how to do those parts online.

Moving the F2F Parts of a Course Online

In a face-to-face course, what is typically done *in the classroom* is some combination of one or more of the following: content delivery, in-class activities, and assessments (quizzes, exams). Taking these one at a time, we can break down converting a F2F course to online delivery systematically.

Content Delivery:

There are many methods and tools to help with moving content delivery online, as well as pedagogical reasons to do this even for F2F courses. More interactive teaching methods already move a lot of the content delivery parts out of the classroom anyway. Examples of approaches to do this vary from trying to closely simulate the classroom environment to completely replacing "lectures" with introducing students to content via other methods or media. An exhaustive review of ways to move content delivery online is not provided here, but below are some options to consider.

One option is to stream lectures live at scheduled times, mimicking how a F2F class would be offered. This can be done with or without an audience response and feedback system in place, which if used can allow for students to ask questions, provide responses, etc. The streamed lecture can be captured and posted so those who cannot attend at the time can watch later, anyone can re-watch parts, etc. Lectures can instead be recorded in advance and posted online as videos. This option allows more timing flexibility but removes the real-time questions/response interaction option. Lectures can be scripted ahead of time or "recorded live" – done as you would present to the class but recorded instead.

Moving a bit further from traditional lecturing, another approach would be to create screencasts – bite-sized chunks of material such as example problems, single concept explanations, explaining a graph, etc. – by recording the computer screen along with verbal explanations and saving as a video file. Screencast skeleton notes [6] offer students the option to print a skeleton of the notes accompanying a screencast and fill it in as they watch and listen. Then students can have a hard copy of notes that closely resemble what would otherwise be presented in the classroom, while also having the flexibility of watching the delivery whenever, at whatever speed, and as many times as they need. Students can choose to write everything that is presented in the screencast instead of using the skeleton notes if they prefer their own handwriting, assimilate information better by writing it all down, or just want to do that. Others who learn well by simply listening can choose to write nothing at all, write their own version of notes, doodle as they listen – whatever they would do in the classroom during lecture time anyway. Given that they can also watch when and where it is convenient and comfortable for them (within your course schedule, of course), screencast skeleton notes have the potential to help students with a variety of learning styles, schedules, processing speeds, etc. gain and retain information better than similar in-class content delivery. Again here, the real-time question/response interaction is missing. That element can be replaced with virtual office hours, a course facilitator responding regularly to email, online discussion boards, and online peer groups.

Supplementing or potentially even replacing "lectures" (including screencast skeleton notes) with other online resources may also be considered. For example, if a textbook is used for the course, the instructor can create guided reading assignments to help the students learn what is important from the instructor's point of view, clarify concepts, etc. Interactive textbooks and publisher tools like WileyPLUS [2] and McGraw-Hill Connect [3] also offer opportunities to help students master material from reading texts. Some online texts such as the one used for the online MEB course in this paper (Felder, Rousseau, and Bullard's Elementary Principles of Chemical Processes) also have embedded videos within them that help illustrate concepts, problem-solving techniques, etc. The screencasts, conceptests, simulations, modules, and concept inventories available on learncheme.com [4] and through the AIChE Concept Warehouse [5] also provide a plethora of digital content to supplement textbooks, notes, etc. as part of the content delivery piece of a Chemical Engineering course.

"In-Class" Activities:

It may be tougher to envision moving in-class activities online…after all, there is no literally "in-class" time in an online course. However, with engaging elements such as SCORED discussion prompts, Zoom sessions, and online peer group assignments to name a few, interactive pieces can also shift online.

For example, one great interactive and constructive in-class activity in the F2F MEB course involved working with the psychrometric chart. Students were given a handout of the psychrometric chart in class after learning about air humidification concepts. They were asked to study the chart in groups, discussing what they could glean from the axes, curves, values, etc. for about 8-10 minutes. Then groups reported out what they figured out and what still confused them as the course facilitator summarized their findings on the board, asked probing questions, etc. For the online course, this activity converted to a great SCORED discussion prompt in which all 12 students got deeply involved and helped each other figure it all out online. This is an example of asynchronous engagement, as the students posted at different times rather than talking directly with one another.

There are also mechanisms whereby students can interact synchronously online. For example, the conferencing function in Canvas can allow students to enter virtual breakout rooms and work on a virtual whiteboard together, where they can hear each other via their computers' microphones, share their screens with each other, and write on a common "whiteboard" on their computer screens. Virtual breakout rooms are also available and easy to use in Zoom and other conferencing packages. This psychrometric chart activity could be done with peer groups of whatever size (maybe 2-4 students would be good for such an activity) synchronously using breakout rooms in conferencing software. This could be even better than in-class group work in some ways because the breakout session can be recorded, so students and/or the facilitator can review later; each student is on their own computer, so has easy access to the "handout" and the "whiteboard"; and the facilitator can instantly pop from one group to another when a group virtually "raises its hand", rather than having to physically walk across a room. The facilitator can also call all students in breakout rooms back to the main room in an online conference, just like the instructor calls for attention back at the front of the room in a classroom. However, in the online version the facilitator can monitor and even force the side conversations to end by stopping the breakout sessions (or can choose not to do so if they want the side conversations to continue), which we cannot always do in a classroom. Tools like this can make it relatively easy to port other in-class activities such as interactively completing worksheets, working problems, and presenting results, to an online version of the activity as well.

Hands-on activities such as labs may be significantly more difficult to move online. Depending on the activity, it may be possible to do it at home. For example, Red Rocks Community College has in the past offered Chemistry labs online, shipping lab supplies to the student and having them do the experiments at home and report on the results online.

Some hands-on activities cannot be shipped in the mail though, and some of the learning outcomes of hands-on experiments may be very difficult to impossible to gain through virtual labs. Take the Unit Operations course in Chemical Engineering – we are not going to be shipping distillation columns, heat exchangers, pumping and piping systems and the like to students' homes. The Unit Operations Laboratory course at Mines is an outlier in many ways (number of experiments run, way in which it is administered) amongst Unit Ops courses nationally [7] and has a longstanding history of being the most highly touted part of our degree, by alumni, faculty, and recruiters alike. [7]-[11] Safely operating equipment, learning how to troubleshoot a set-up when it is not functioning as expected, hearing and feeling what happens when a pump cavitates or a fluid system experiences water hammer are just a few examples of learning outcomes students would mostly or entirely miss with only virtual labs in place of hands-on labs. Gaining the confidence in their own ability as engineers through turning valves and operating actual equipment is another. It is the author's opinion that courses like this should not be moved completely online unless there is no choice.

In dire circumstances such as this year's pandemic, a substitution course for a course like Unit Ops can be developed, with the recognition that not all of the learning outcomes can be met in this way. Workshops can be moved online using the methods mentioned above for lecture-type F2F courses. Virtual labs can be created to simulate lab experiments online, offering some of the learning outcomes of an otherwise hands-on lab experience such as seeing how changing some conditions affects other conditions in an experiment. Videos of the actual equipment can be made to show students what controls they would have, what the system looks and sounds like when it is running, what measurements they would make, what the analysis equipment looks like and how it works. Pre-measured or computer-generated data can be given to students so they can do data analysis. Conferencing software can be used to do pre-labs, let students give oral presentations, conduct draft reviews of written reports, and even run weekly general meetings, thereby simulating the F2F interactions associated with such a course.

Assessments:

Quizzes and exams are typically (though not always) designed to be individual activities anyway. When they are meant to be individual activities, they are the last things we want to have done in a classroom, where students are all close to each other, working on the same or similar problems, eyes may wander, the environment may not be ideal for thinking, and so on. Imagine if instead each student could take exams in their own comfortable space where they cannot see each other's papers and the instructor could actually see them working the whole time and even hear them explain their thinking. Imagine further that as soon as the exam is submitted, at least part of it is immediately graded. That is what an online exam can potentially be. As long as the integrity of the online testing process can be ensured, online tests might be preferable over in-class on paper tests even for F2F courses.

This brings us to another common concern about online courses…

<u>Ensuring Assessment Integrity</u>

For anything typically done outside of the classroom anyway (homework, projects, class preparation assignments, etc.), this concern is not specific to online courses. For exams and quizzes, one can potentially be even <u>more confident</u> in an online environment than in a F2F environment that the work credited to a given student is their own. This can require significant resources, if one chooses the policing route, but is possible as outlined below. Alternatively, one could take the approach of designing quizzes and tests that allow students to use a broader array of resources (internet, book, notes, maybe even each other, etc.) to minimize the monitoring requirements. This second option also comes closer to mimicking what students will be asked to do "in the real world". Use of this approach may require creative assessment methods though, such as having students create a video of themselves explaining their solution, results, thinking. Even if they had help getting to a solution, if they can explain it well on their own, that may be sufficient to assess they have met a particular learning outcome.

The approach taken in the Summer MEB example highlighted here to ensure quiz and exam integrity was to:

1. Run quizzes and exams synchronously – assures no sharing of problems ahead of time
2. Write new problems for each assessment (or have such a large bank of problems and questions that re-using some will not give an advantage to students who have access to past assessments)
3. Use proctoring software that records each student's computer screen and the room around them simultaneously throughout the online assessment
4. Have students upload their handwritten work, done on initially blank paper, immediately at the end of the assessment
5. Have students record a short video of them explaining their solution to a problem as part of the online assessment

<u>Writing Good Questions for Online Assessments</u>

For the Online MEB course, each quiz and exam was a set of online problems programmed into Canvas. A wide range of problem types (multiple dropdown boxes, matching, T/F, multiple choice, fill in the blank, short calculation, longer calculation, essay) was used throughout the course. Conceptual questions were designed to be easy to answer if the student really understood the concept, and not likely to be answered correctly if the student did not. Fill in the blank questions or short calculations based on a concept (for example a manometer or chart reading question) can fit this bill.

Multiple Choice with Partial Credit:

Consider giving multiple choice questions with *a-k* (now that ABET has abandoned a-k, we can use it for this instead!) or even more options instead of *a-d* but allowing for partial credit for partially correct options amongst the many choices. For example, a multi-part calculation problem could have *a-k* options with *b* being the correct answer (full credit), *f* being a common distractor (partial credit based on concept missed to get that incorrect answer), *a* another common distractor (different partial credit since different concept missed to get that one), *e* the answer if they made both of those mistakes (lower partial credit since 2 mistakes made), and the other options being values close to each of those common mistake answers so they cannot just guess order of magnitude (each of those worth no points). Including an option of "none of the above, the answer is ________" (and let them fill in the blank) as an option, *and having that be the right answer sometimes so that students do not automatically reject it*, is another way to consider offering partial credit on a multiple choice question.

Other Concept Question Types with Partial Credit:

You can also write clever questions that can be easily graded, even with partial credit, by writing "check any and all that apply" and having checkboxes with options, even including a blank option where they have to add something if it is not there. For example, you might ask students to identify what assumptions must be valid for a given equation to apply with a question type like this. In addition to being relatively quick to answer if the student really understands, and automatically gradable even with partial credit, questions like this can test higher order thinking skills better than plug and chug calculations, simple *a-d* multiple choice questions, etc. There is an art to writing good questions like this, but it is one worth taking the time to practice. Using this approach in the Online MEB course, most concept questions were automatically graded by Canvas.

Formula Questions for Calculations:

For problems that involve calculations, you can program the online assessment with formulas such that students get different input values to use. This was done directly in Canvas for the Online MEB course as an added level of security to prevent students passing numerical answers on to each other in some way, though it was not really necessary since students had to be alone in a room with their computer with webcam to take the quizzes and exams. Short calculation problems worth a fraction of the overall assessment score could be graded as all or nothing. In the Online MEB course for longer, multi-part problems, the students' submitted handwritten work was graded for partial credit and their video explanations were graded as well. In this course the video explanations were a small part of the grade and were used to assure that the student could explain their own written problem solution rather than being scored based on the correctness of the solution itself, which is how the handwritten work was scored. Alternatively, the explanation could provide the majority of the score for a problem.

Monitoring Software:

Exam monitoring software options are commercially available. In the Online MEB course, the monitoring software (ProctorU at the time; now we have switched as a campus to Proctorio) allowed the course facilitator to control and see what the students had access to during the test. Settings for things such as whether or not the students could have bathroom breaks, if they could use notes or not (they were allowed 1 handwritten note sheet, which they showed to the webcam at the beginning of the assessment), what other sites (if any) they could navigate to during the assessment, whether or not they could minimize windows on their screen during the assessment, whether or not they could have other devices on in the room, if other people were allowed to be in the room, etc. could all be "controlled" in the software. The facilitator did not need to watch all videos. If there were concerns picked up by the software based on the controls set by the facilitator, the video would be flagged at that point. Parts of each video were watched, at up to 5x speed, to check for the software's accuracy in flagging issues, which was good. In a larger course, this is something a grader or TA could do. *However, just the knowledge that they are being recorded likely prevents or at least reduces cheating for the most part.*

<u>Recorded Explanations for Enhancing Learning</u>

The recorded explanation part of the assessments was initially added for the purpose of ensuring exam integrity. However, the explanations ended up being even more useful as metacognition tools for the students. Since students had to record explanations on exams, they were given the opportunity to practice that on each problem set and quiz as well. The course facilitator watched these short videos after each problem set and quiz and gave the students individualized feedback based on their own thinking. Students often realized as they were explaining things that they had them wrong and fixed them on their own. In the end it proved to be such a useful metacognition tool that the author ended up using this in F2F courses later for the purpose of helping the students understand the material better. Though in the large (>140 student) F2F courses where this was used in the Fall the course facilitator did not even watch the videos, let alone provide any feedback, some students reported the recorded explanations as the most useful part of the course due to the level to which they had to understand a problem in order to explain it.

<u>Designing Online Courses for Student Success</u>

As mentioned previously, a concern about online courses in general is that students do not tend to be successful in online courses unless they are highly self-motivated and self-disciplined. This concern assumes a picture of online courses that is not necessarily accurate – i.e. that online courses consist of offering content in some form or another to students on an online platform, perhaps with some suggested activities to practice working with the material, and then summative assessments to see how well the students have done. Students are assumed to be on their own to sink or swim with the material. Indeed it would be difficult for students to be successful in a course like MEB if this were how the course were run. In particular, students who have struggled with the course once before and likely need even more support would be extremely hard-pressed to succeed in a course like that.

This is not how online courses at our institution run. To offer an online course here, course facilitators (professors) must:

1. Take a 5-week online Engineering and Facilitating Online Learning (EFOL) course teaching us how to design and facilitate an effective online course.
2. Begin to design our course with SMART [6] (Specific, Measurable, Achievable, Relevant, Time-bound) Learning Outcomes (LO's), a solid course map, a useful syllabus, and sample assessments and rubrics, all of which the EFOL course teaches. Taking the EFOL course, professors experience what it is to be a student in an online course. We learn how important all of the required elements of a good online course (clear schedule and expectations, frequent and useful feedback, connecting with other participants through useful discussions, etc.) are.
3. Work with an OLED (Online Learning Experience Designer) for 12 weeks to build the whole course including all modules, assessments, rubrics, etc. In the end each module has an overview showing how each course element (assignment, reading, video, discussion, quiz, etc.) in that module maps to the overall course LO's and gives the student a schedule with anticipated time allotments for completing the module. The course must show evidence of frequent check-ins and opportunities for quality feedback to be provided to the participants throughout the course.
4. Once the course is built it gets reviewed for compliance with the standards by an Online Standards Committee consisting of our teaching and learning center's faculty and staff as well as academic faculty from various departments across campus.
5. When the course is running, the OLEDs serve as coaches to help the faculty member make adjustments to the course. Mid-course evaluation surveys are conducted and adjustments may be made based on those responses as well.
6. After the course runs the teaching and learning center faculty and staff help the faculty member reflect/modify the course based on data including student evaluations.

Due to the scheduling, frequent check-in points and feedback, and required engagement between participants and the instructor, it would be more difficult for an online student here to fall off the radar and get left behind than it would be for a student in a F2F class to do so.

This level of support is offered so that the standards can be met so that online students will have the greatest opportunity to be successful. Considering these standards, it may be easier to understand how the Online MEB course in fact ran very similarly to the F2F versions – with frequent graded assignments, class prep and participation points to keep students accountable, frequent quizzes, regular opportunities (and requirements) to interact with other students and the instructor, and a midterm and a final exam. It takes a lot of time to develop such an online course and also a lot of time to facilitate it as the course is running. This level of support may not be available at all institutions. However, knowing these standards to try to meet and considering how to design an online course to parallel a F2F course in terms of opportunities for students to engage more fully can help move anyone toward offering a successful online course.

<u>Online vs. F2F MEB Course Offerings</u>

Table 4 gives a side-by-side look at how the online course was structured compared to Spring and Summer F2F offerings of the same course by the same instructor. Ten percent of the course grade was for "homework" assignments in the F2F courses and "problem sets" assigned in the online course. The problem sets were equivalent in difficulty, quantity, and distribution between online and written problems to the homework assignments in the F2F offerings. In the online version, there were also SCORED discussion prompts as part of the 10% homework-equivalent grade. Those discussion prompts were graded based on quality and replaced some in-class activities from the F2F courses. Class prep and participation (CPP) accounted for 5% of the course score in all offerings. That was completion based in the F2F courses and consisted of online WileyPLUS reading assignments and a few in-class exercises (which became some of the SCORED discussion prompts in the online version). In the online course the same WileyPLUS reading assignments were also assigned and scored based on completion. Posting meaningful responses to others' initial discussion posts also added to the CPP score in the online version.

Quizzes and exams were the same level of difficulty, written with similar problems, had the same relative emphases on concepts vs. calculations, and covered the same course material (all chapters of Felder, Rousseau, and Bullard) for all three offerings. There was a project in the Spring F2F offering but not in the two summer offerings. The 10% of the Spring F2F course score transferred to an extra 5% each for the midterm and final exam in the Summer offerings. Quizzes accounted for 30% of the course score in all offerings.

Table 4 – Course structure in Spring F2F, Summer F2F, and Summer Online MEB offerings by the same instructor.

Spring F2F MEB	**Summer F2F MEB**	**Summer Online MEB**
16 weeks	6 weeks	8 weeks
Homework – 10% ~1/week Part online (WileyPLUS) Part handwritten	Homework – 10% ~1/week Part online (WileyPLUS) Part handwritten	"Problem sets" and Discussions – 10% ~2/week Part online (WileyPLUS) Part handwritten
CPP – 5% WileyPLUS reading assignments In-class participation	CPP – 5% WileyPLUS reading assignments In-class participation	Course participation – 5% WileyPLUS reading assignments Responses to discussion posts Attending Zoom OH
Quizzes – 30% ~1/week ~20-30 minutes in classroom Q&A before quiz	Quizzes – 30% ~2/week ~20-30 minutes each in classroom Q&A before quiz	Quizzes – 30% ~2/week ~30-45 minutes each online (Canvas) Zoom session before quiz
Midterm – 20% Week 8 1.5 hours Common Exam time Office hours before exam	Midterm – 25% Week 3 2 hours in classroom Office hours before exam	Midterm 25% Week 4 2.5 hours online (Canvas) Zoom session before exam
Final Exam – 25% Week 16 2 hours	Final Exam – 30% Week 6 2.5 hours	Final Exam – 30% Week 8 2.5 hours

Common exam time Review session before exam	in classroom Office hours before exam	online (Canvas) Zoom session before exam

For each 2 weeks in the Spring course, the online course spent 3-4 days covering the same content and doing the same activities and assessments. Students were expected to spend 10-12 hours within those 3-4 days on that "module". The module-level structure included:

- Module overview: 0.5-1 page showing module description, outcomes, activity/task/time listing
- Notes and screencasts (replaces in-class "lecture" time): 4-12 page PDF of skeleton notes with several 3-10 minute screencasts walking through the notes. This is one option for students to gather the content, but it is not required to use them. Alternatively, students can read the text, watch the embedded videos in the text, etc.
- Reading assignment (same as in F2F): Online LearnSmart reading assignments go along with each chapter as course prep and participation (CPP) points
- Problem set (same as homework in F2F course plus recorded explanation)
    - WileyPLUS part (3-4 problems, scaffolded, no penalty for unlimited tries)
    - Paper/Recorded Explanation part (3-4 problems on paper, submitted as a PDF along with a recorded media file explanation of one of the problems)
- Problem set solutions post so students can study before Zoom office hours (same for F2F)
- Zoom office hours (replaces F2F office hours): Run Zoom meeting in "Zoom room" where students can conference in – with audio or video or both or just type in the chat window. Zoom sessions are recorded and posted to Canvas so those who cannot attend can benefit from them too.
- SCORED Discussions (replaces in-class activities in F2F course):
    - Students post to prompt by set time
    - Students respond to posts in meaningful way by later that day or night
    - Facilitator enters discussion where they can help fix misconceptions, guide to resources, etc.
- Quiz (same as in F2F except done online): done synchronously so students cannot share information about quiz
- Quiz solutions post shortly after quiz is completed (same for F2F)

In summary, the F2F "lectures" were converted to screencast skeleton notes [6], the office hours were replaced with online Zoom office hours, in-class activities were replaced with SCORED discussion prompts, in-class assessments were replaced with equivalent online assessments, and the rest was effectively the same. The Zoom office hours had the added advantage of being recorded so students who could not attend one at the time it was offered could watch/listen to the recording later. This advantage led the author to offer Zoom office hours for F2F courses as well. As there were only 12 students and they all quickly became engaged in the course and interacted well and frequently with each other online, groups were not created within the 12. Considering scaling up to a larger online course, one might create groups of 8-12 to mimic the productive level of interaction experienced in this pilot course.

Engaging Students through "SCORED" Discussion Prompts

Zoom office hours and regular synchronous assessments were two key elements making the online course engaging. Combining these with the facilitator's continuous attention to the engagement levels of the students and reaching out to them if they slipped behind (within 24 hours), students were as engaged or moreso in this course than in past F2F versions. One of the most engaging components of the course was the "SCORED" Discussion Prompts. To keep the discussion posts sufficiently engaging and from becoming bland, which could easily happen if the students just had to read something or watch something and "comment on it", each module's discussion prompt needed to be SCORED:

- SMART (Specific, Measurable, Achievable, Relevant, and Time-bound) [6]
- Connecting: Something that students were likely to find interesting, helpful, relevant to something they cared about in life, etc. and would thus connect them with the material *and* connect them with the facilitator and each other
- Original: Worded in such a way that they were not likely to give the same answers as each other or some generic answers they could find from someone or somewhere else
- Revisited: Posted to before they could see others' responses, by a given time on the discussion due date, and then gone back to later so they would read each other's posts and respond to them
- Engaging: Interesting enough that the students would get excited about offering their posts to the discussion and be internally driven to come back and read others' posts and comments on their posts
- Diverse: Varying in content and focus so prompts would not become predictable, follow the same format each time, etc.

This is actually a rather challenging, but fun, exercise to undertake. In the presentation accompanying this paper, the 13 SCORED discussion prompts from the first Online MEB offering will be described briefly. Some will need to be changed for the next offering to keep them original, but some can be kept. One example was the psychrometric chart mentioned above – students were asked to spend exactly 10 minutes studying it and writing down whatever they could interpret from it and whatever they noticed that they did not understand from it. For the "homework" part of their discussion score they had to post those "gots and needs" to the discussion board. Once they posted they could see each other's posts, which were all due by 5 p.m. on a given day. Then by 8 p.m. that same day they had to respond meaningfully to at least two other students' posts. They got CPP credit for that revisited post. They got so into this activity it was incredible. One student found external resources walking through psychrometric charts that they posted for others to see, one student made their own color-coded version of the chart and made a video explaining it, and all but two of the students posted several times (in meaningful ways) to the discussion well after their "graded parts" were due.

The discussion posts were one of the most engaging elements of the course. For most of the prompts students posted significantly more in terms of quality help for each other, deep explanations of personal interests related to the topic of the week, quantity of meaningful responses to each other, etc. than was required. For more than just the psychrometric chart prompt they created materials they posted there to help each other that were so good the course facilitator asked if she could have them to use for later offerings of the course.

The author has not personally witnessed that level of engagement in any F2F course she has offered.

Student Evaluations of the Online MEB Course

Student evaluations were very positive. Table 5 shows how students scored the course in terms of several prompts.

Table 5 – Course Student Evaluations: For prompts 1-11 answer options are a Likert scale from Strongly Disagree (1) to Strongly Agree (5). For prompts 12-14 answer options are a Likert scale from Never (1) to Almost Always (5). Eleven out of 12 students responded to all prompts listed. "X" = course facilitator's name. Prompt 15 was students' anticipated grade (1 A, 6 B's, 3 C's, one did not answer).

1 – It was clear what I was supposed to learn in this course.	4.64
2 – Course assignments helped me develop the skills I was supposed to learn in this course.	4.55
3 – X provided feedback on coursework in a timely manner.	4.82
4 – X provided feedback on coursework that supported my learning.	4.82
5 – X created a positive learning environment.	4.64
6 – X cared about students' learning.	4.82
7 – X encouraged student questions and feedback	4.82
8 – X made the content relevant to my field of study	4.73
9 – The course was a worthwhile experience.	4.82
10 – I would recommend this course with X to others.	4.91
11 – Overall, X taught this course in a way that advanced my skills or knowledge in this field.	4.82
12 – I consistently prepared for this course.	4.18
13 – I turned my course assignments in on time.	4.36
14 – I put forth my best effort in this course.	4.36

For prompts 1-11 (about the course and the facilitator) there were 0 responses below Agree (4) and most were Strongly Agree (5). Interestingly, students were slightly *less* positive in their responses about their own efforts!

Students' Written Comments:

When asked what aspects of this course were most effective in helping them learn and what made those things helpful, student responses emphasized:

- Rigor, focus on concepts: screencasts explaining concepts rather than just problem solving; connections to applications and industry (highlighting relevance); one mentioned learning "so much more" than they did in the F2F course previously (but acknowledged could be due to repetition)

• Engagement with others: the level and quality of student-to-student and instructor-to-student interactions through the discussions, Zoom sessions, and email exchanges; students said that made it both easy and desirable to learn the material

• Flexibility: to complete the required material on their own time and then participate in Zoom sessions or email the instructor with further questions; ability to pause screencasts and go at own pace, which cannot do in a traditional lecture
• Consistent week layout/course structure and feedback: made it easy for students to pace their own learning and not get behind. Specifically students liked the multiple ways each problem set was submitted (WileyPLUS problems allowing for practice without penalty and providing helpful hints, then on paper problems with explanations), then a discussion, then a Zoom sessions, then a quiz for each chunk of the course (1/2 week, in this case)

• Recorded explanations: provided a chance to explain thinking and work though problems step by step while getting immediate feedback

When asked what changes could be made to make the course better, student responses emphasized:

• More: one would have liked to have more *screencasts* and example videos; one more *interesting* or thought provoking *discussion prompts*; one more *flexibility* regarding when quizzes were taken (making them asynchronous instead of synchronous – new issues arise there)

• Clarify expectations better: one student didn't realize they needed to get some information out of the text in addition to the skeleton notes. Example given was the equations for the variables in the SRK equation of state, which were not outlined in the skeleton notes but were needed for the problem set and quiz.

• Better alignment: two students mentioned that sometimes quiz questions were covered in detail in later notes and saw this as an alignment issue. This is really a communication issue, as when that happened it wasn't because the quiz came too early relative to the notes but because the quiz problem was revisited to improve understanding and connect concepts to the next material.

• Better connections: one student felt homework sometimes seemed to "come from a different text" (real problem there is that they didn't feel equipped to do the problem(s) since problems shouldn't feel tied to a textbook anyway)

So overall students seemed to appreciate the structure, flexibility, engaging elements, and rigor of the course. Better communication about the need to refer to text and why past quiz problems are sometimes revisited in later modules, and more: screencasts, interesting discussions, and flexibility, would improve the course. Asynchronous quizzes could be considered, but then other methods to prevent "cheating" would need to be applied to keep the playing field even. The level and quality of engagement in the discussions by most students indicated that the SCORED discussion prompts were interesting to most students and definitely helped them understand things better and highlighted trouble spots so more help could be provided. The fact that one student found them not interesting enough highlights the need for the C and D parts of the mnemonic – Connecting (ideally for everyone) and Diverse (to reach more students' interests).

Conclusions

A fully online version of Material and Energy Balances was offered in an 8-week Summer II session in 2019 at the Colorado School of Mines to a cohort of 12 students. The course outcomes (pass percentage, quiz and exam averages) were not statistically different from those for typical Spring 16-week and Summer 6-week F2F offerings by the same instructor. One can approach moving a course or part of a course online by systematically considering each typically in-person element of a F2F course: 1) content delivery, 2) in-class activities, and 3) assessments. For the online MEB example presented here, screencast skeleton notes and online textbook resources were used to move the content delivery online. The in-class activities were replaced with SCORED discussions and Zoom sessions. Quizzes and exams were moved online closely mirroring the F2F course by holding them synchronously and using proctoring software to ensure integrity of the test taking process. Assessments had the same types of questions (conceptual and detailed problem-solving calculations) and difficulty level as those in the F2F courses and were partially automatically graded and partially graded by hand. The Online MEB course offered in this way was highly engaging and effective, leading to 11/12 students technically passing the course, with 10 of those at the C- or higher level sufficient to move on to the Junior core courses, Fluids and Thermo. The Summer MEB students overall (F2F and Online) passed both subsequent Junior core courses at a lower rate (66%) than the average for all students taking both of those Junior courses (84%). Differences in the Summer cohort (80% repeaters in summer vs. < 5% repeaters in spring) <u>and</u> in the summer course (concentrated single course at a time, smaller class size, more individualized feedback in Summer) compared to the overall class make up and typical academic year course schedule are likely contributors to this discrepancy in performance of the two groups. Better scaffolding support during the Summer courses to enhance students' abilities to learn more independently may help better prepare them for success in the Junior core courses.

Acknowledgements

Thanks to everyone at the Trefny Innovative Instruction Center for creating the Engineering Learning framework (Sam Spiegel), offering the EFOL course (Rebecca Reese, Susannah Simmons), supporting development of this online course (Ana Lopez, Jennifer Veloff), and helping the author obtain the necessary training and approval to conduct and present this study (Megan Sanders). This course, the decreased time to degree it offered these students, nor the comparative study of Summer vs. Spring MEB (let alone Online MEB) would have existed without this very important center and its wonderful people!

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