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Pedagogically Grounded Techniques and Technologies for Enhancing Student Learning

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ABSTRACT

Many engineering courses rely on in-person lectures and textbooks for content delivery, with homework sets and exams for evaluating and reinforcing student progress. Yet some research studies have shown that exams—high-pressure, time-limited assessments—are detrimental to the learning process and unnecessarily increase students' stress. We describe a new student-centered teaching approach based on four pedagogical domains: scaffolded, universally-designed, mastery-based, and gameful learning. The approach was implemented in an engineering course by first chunking the content into small, easily digestible topics. Next, multiple modalities were used to deliver this content, including textbook references, virtual lectures, condensed presentation slides, summary sheets, and two-minute videos. Finally, the typical grading system was replaced by a point system using multiple 10- and 20-point quizzes, all of which could be attempted multiple times through unique versions for each student. Several findings emerged from our examination of this overall instructional strategy. The flexibility in learning and assessment enhanced students' mastery of content and maximized their sense of ownership in the learning process. The multiple attempts on quizzes provided the students with more freedom to fail and resulted in a more supportive learning environment. Last, the multimodal delivery and self-controlled assessment process promoted inclusive and equitable learning. This course structure can be translated to many other engineering courses, with spreadsheets and a web-based quiz making program developed to assist in the process.

BACKGROUND

Conventional lecture-based university courses, with periodic homework assignments, two or more exams, and a cumulative final exam as the chief means of assessment, do not align with best practices in education. Instead, research indicates that interactive teaching with regular formative assessments enhances university students' learning and engagement in engineering and other STEM fields (Felder et al. 2011; Freeman et al. 2014; Qadir et al. 2020; McCallum and Milner 2021). Even as some engineering faculty members hold tightly to traditional methodologies, others have long experimented with alternative instructional and assessment strategies (Olds et al. 2005; Moore 2016; Halls et al. 2021). In 2019, Brito et al forecasted that engineering education would be radically disrupted by various emerging technologies, from artificial intelligence to the internet and cellular phones, resulting in a blending of digital and physical worlds. Even so, few could have anticipated the seismic instructional changes wrought by the pandemic.

Re-designing a university course is rightly understood as labor-intensive under the most ordinary conditions, but all the more when shuttered physical classrooms force a rapid transition to virtual instruction and heighten stress for faculty members and students alike. Yet these same challenges have accelerated the implementation of innovative instructional approaches in engineering education, as demonstrated in a special issue of *Advances in Engineering Education* dedicated to engineering educators' responses to COVID-19 (Chen et al. 2020). For a faculty member returning to the classroom after a decade-long administrative hiatus at the University of Michigan—and entering a fully virtual classroom for the first time—these conditions prompted the overhaul of a traditional chemical engineering fluid mechanics course.

Offered the second semester of each academic year, ChE 341 Fluid Mechanics is comprised of approximately 100 sophomore engineering majors traveling through a sequence of courses as a cohort. The fluid mechanics course is taken concurrently with a course in thermodynamics, following students' two introductory engineering courses in their first year of study and a mass/energy balance course the first semester of their sophomore year. Providing three 50-minute class sessions each week, a faculty instructor oversees two graduate student instructors who run 50-minute weekly recitations, as well as two undergraduate instructional aides and one undergraduate tutor.

With the goal of creating a modernized student-centered class, the lead professor and the broader instructional team drew upon the literature from the pedagogical domains of scaffolded, universally-designed, mastery-based, and gameful learning. The course transformation process involved chunking the content into mini-units, delivering content through a range of modalities, and relying on a single assessment strategy of randomized short quizzes. Though inspired, in part, from the demands of online teaching during a pandemic, these revisions have proven fruitful enough to warrant a lasting place in the engineering classroom.

PEDAGOGICAL DOMAINS

In alignment with evidence-based best practices, the restructured Fluid Mechanics course was founded on the pedagogy from four complementary instructional strategies: scaffolded (Dennen 2007), universally-designed (Rogers-Shaw et al. 2018), mastery-based (Bekki et al. 2012), and gameful learning (Ajlen et al. 2020; Walker et al. 2020). First, scaffolding refers to instructional techniques that support students' incremental movement toward deeper understandings of content and independent exercise of knowledge. Like the scaffolding that is constructed to assist workers in reaching ever higher locations in building renovation, these forms of support are used to help the student progressively ascend to more complicated concepts. While scaffolded instruction can take various forms, a common practice is the division of more complex content or skills into smaller, discrete parts, which helps minimize students' experiences of frustration or discouragement (Dennen 2007).

Second, the Universal Design for Learning Guidelines (UDL) developed by the Center for Applied Special Technology (CAST) have been integral to the redesigned ChE 341 course (Rogers-Shaw et al. 2018). The UDL guidelines set out a framework that not only expects variations among students' abilities, backgrounds, needs, and preferences but also aims to optimize teaching and learning for all people across any discipline or domain. Striving to accomplish inclusivity and equity among learners, this model provides a high level of flexibility in the way that class content is presented, students are engaged, and students demonstrate their understanding. A closely related but distinct pedagogical philosophy, attributed to linguists Kress and Leeuwen (2001) and indebted to the neuroscience of learning, is multi-modal instruction, which provides learning opportunities in a variety of forms to accommodate visual, auditory, read write, and kinesthetic learners.

Third, the ChE 341 course draws upon mastery-based learning, also known as mastery learning, an approach that has received growing attention and use in higher education following its wider adoption in K-12 settings (Bekki et al. 2012). Mastery learning is typically distinguished by three key features, based on the germinal work of Benjamin Bloom (1973): 1) class content is divided into discrete learning units that are linked to mastery-based assessments; 2) assessments are used to measure mastery, often defined as achieving 70%–90% of a possible maximum score, ideally accomplished through an unlimited numbers of retakes; and 3) the instructor provides feedback on each assessment, which can range from basic indications of correctness to more substantial guidance for students' improved performance on retakes (Perez and Verdin 2022). By presuming that all students can learn a concept when given enough time and practice, mastery learning normalizes learning from mistakes and rewards continuous improvement and persistence rather than inherent ability (National Academies 2016). Rather than moving all students through content at the same pace and accepting minimally adequate performance on assessments, mastery learning provides opportunities for repeated attempts before students

proceed to the next topic. Mastery learning bears resemblance to competency-based progression, which emphasizes students' self-determined pace of advancement and readiness for assessments, as well as personalized learning, which customizes instruction to students' particular needs and goals.

Last, the ChE 341 course enacts gameful learning, a pedagogical approach inspired by well-designed games and self-determination theory (Ajlen et al. 2020). Proponents identify several key components of students' intrinsic motivation: being able to make meaningful choices (autonomy); being challenged by a task yet feeling capable of success (competency); and feeling connected to those around them (belonging). Accordingly, gameful learning tends to prioritize students' ownership of their learning, immediate feedback on learning attempts, and opportunities to fail safely and try again—echoing some of the key tenets of mastery learning. Rather than starting with a grade of 100% in a class and losing percentage points, students start with zero points and "earn up" according to specified attainment values. In some instances, students' mastery of one level of play/learning is rewarded by a digital badge or other visual recognition that qualifies them to progress to the next level (Walker et al. 2020). As Fishman and Hayward observe, gameful learning runs counter to conventional school experiences, which may feel to students like a "bad game" that encourages maladaptive behaviors such as preoccupation with grades and following rules and instructions over authentic learning and creativity (2022).

Underlying these pedagogical approaches were some core beliefs held by the faculty instructor and shared with the instructional team. Foremost, it was assumed that, as vetted and admitted students in Michigan Engineering, all participants in ChE 341 could be successful, given the proper support and sufficient opportunities for practice and learning from mistakes. While this confidence in students' capacities for learning may seem unremarkable, gatekeeping cultures can still plague the engineering discipline. Regrettably, the American Society for Engineering Education (ASEE)'s 2016 Retention and Time-to-Graduation Survey report reveals that, between 2008 and 2013, less than 50% of students who enrolled as first-year students in engineering ended up graduating with that degree within four years. The highest levels of attrition occur during students' first two years of study, a period that coincides with the timing of this fluid mechanics course (2016). Notably, research on engineering students' attrition and persistence indicates that students frequently cite competitive, exclusive environments—rather than low grades—as the reason for their departures from engineering majors (Wallwey et al. 2022). A second core assumption was that, given the intense levels of pandemic-related stress that students were enduring, it would be desirable to enact pedagogical strategies that minimized unnecessary pressures. In light of the heightened anxiety that many students experience related to midterm and final examinations, as well as well-researched limitations of high-stakes summative assessments in measuring student learning (Knight 2002; Rust 2007; Yorke 2010), this revamped ChE 341 course relied on frequent formative assessments in the form of randomized online quizzes.

METHODS: PREPARATION OF THE COURSE

Chunking Content

The course transformation process began with the relatively straightforward task of breaking down the course content into easily digestible chunks. Because most textbooks are organized by units and chapters, these subdivisions made for natural breaks in material delivery. Ultimately, the course included five major learning units: basics of fluid statics, basics of fluid flow (no friction/viscosity), process equipment (including friction/viscosity), microscopic analysis, and other/advanced topics. Each of the five units was then divided into approximately ten topics using a scaffolded learning approach. Each topic of material was taught in segments of class periods ranging from 25–75 minutes, roughly corresponding to fifty distinct lectures during a 41-class semester. The topics advanced in difficulty as the student moved through each unit and the semester, with knowledge building up cumulatively. Note that some of the topics were merely example problems that explored applications of fundamental concepts or broadened the original topic discussion.

Developing Different Content Delivery Methods

Inspired by UDL guidelines, the faculty instructor offered a variety of delivery modalities, which took considerably more effort. According to their respective learning styles and preferences, students could select from the following instructional resources for each topic: references to a recommended textbook, a single PowerPoint slide with a high-level summary of key concepts, an extended PowerPoint presentation, a condensed version of that same PowerPoint presentation, and a two-minute summary video. In addition, the faculty instructor generated and presented a lecture on each topic, urging students to take notes by hand in accordance with best practices for learning, and referenced the lecture material, derived largely from *Fluid Mechanics for Chemical Engineers* (Wilkes and Birmingham 2006). The extended PowerPoint presentation was animated and presented online via the Zoom platform during the 50-minute lecture, and the lecture was recorded for later viewing. The Zoom platform allowed the students to view the slides and the professor concurrently, and the students were highly encouraged to ask questions during the lecture. Learning was supplemented with weekly hour-long recitation sections, organized into groups of 25 students and operated by graduate student instructors.

METHODS: PREPARATION OF THE QUIZZES

Single Assessment Strategy

The most significant revision to the ChE 341 course was the replacement of the conventional 8–10 homework assignments, two tests, and a final exam with a single assessment strategy: 93 individualized

quizzes. Although the instructor's workload in accomplishing this change was substantial, most of the effort was due to an initial lack of software to handle the quiz generation—a challenge that was later remedied. For a class size of ~100 students, 300 unique versions of every quiz needed to be produced, each of which was similar in content, complexity, and solution strategy but different in specific numerical values, sentence construction, and sometimes topic. Thus, approximately 30,000 quizzes were needed for the entire course.

The quizzes were designed with a modified mastery-based learning approach. Perez and Verdin's literature review (2022) identifies various experiments undertaken with mastery learning in undergraduate engineering courses, such as the marking of homework problems as mastered or not mastered prior to allowing resubmitted assignments, accomplished either manually (Moore 2016) or via online platforms (Green 2000); and allowing students to retake midterm exams, with each successive retake designed to be more difficult (Armacost and Pet-Armacost 2003) or with reduced points available (Sangelkar et al. 2014). In the case of ChE 341, all assessments were designed as quizzes, including four categories: topic, unit, cross-unit, and cumulative. The students had one week from the date the quiz was assigned to complete the quiz, with the exception of topic quizzes, which the students were encouraged to complete within two days of the related lecture. Unproctored and taken online, these quizzes typically required 15–30 minutes for completion and mainly consisted of only one calculation question. Occasionally, there would be True/False (T/F) or multiple-choice quizzes, but these formats were much less common. Across all four types of quizzes, students received a unique version of the quiz for each attempt and immediate feedback from the online system. For topic quizzes, which allowed for unlimited attempts and had a 30-minute time limit, students would receive the correct numerical answer upon completion of each quiz. For unit and cross-unitquizzes (60-minute time limit), the number of attempts was constrained to three, but studentswould still receive an immediate indication of the correct answer. For the cumulative quizzes (60-minute time limit), the hardest and most complex of the lot, students would have three attempts and would only receive an immediate indication of right/wrong and not the correct numerical answer. Table 1 summarizes the characteristics of the quiz types, while Figure 1 illustrates the overall class assessment structure.

The rationale for having four different categories of quizzes was to structure students' progression through the material by increasing the complexity and difficulty of the assessment. This strategy adheres

Table 1. Characteristics of each quiz type.

Quiz type	Attempts allowed	Content Coverage	Feedback after submission
Topic	Unlimited	Single topic	Correct answer*
Unit	Three	~10 topics	Correct answer
Cross unit	Three	~20–30 topics	Correct answer
Cumulative	Three	~50 topics	Right/Wrong only

*Correct answer was given, unless it was a multiple choice or T/F quiz.

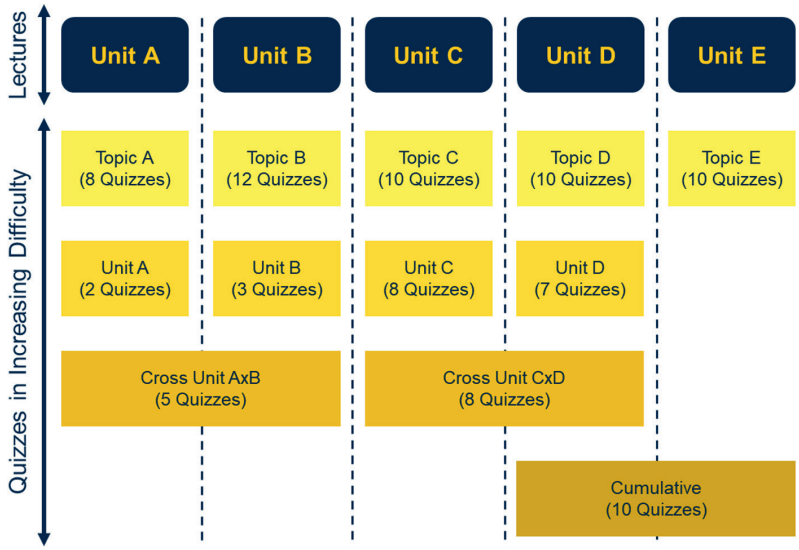

Figure 1. The course material was categorized into five units, with each unit containing 6–12 topics. Quiz assessments were done on single topics, single units, and cross-units. Cumulative quizzes only assessed the last two units of material. The difficulty of the quizzes increases down the figure.

to the principles of scaffolded and gameful learning—challenging students to move to the next level of comprehension by taking quizzes of increasing difficulty, with fewer attempts offered and broader span of topics represented. Note that students would typically not study before taking an unlimited attempt quiz (formative assessment) but would study before taking any of the limited attempt quizzes (summative assessment). For topic quizzes, students' mastery was defined as 100% accuracy, while students could receive partial credit (60% maximum) for their performance on unit, cross-unit, and cumulative quizzes if their multiple attempts didn't ultimately result in 100% correct answers. Unlike some forms of mastery learning, ChE 341 did not prevent a student from progressing to new topics if mastery wasn't achieved, nor did the window for assessment remain open indefinitely. Instead, students had seven days in which to take and retake an assessment, and the students themselves determined when they were satisfied with their level of understanding. And, as shown in Figure 1, there would be different types of quizzes open at the same time. For example, while covering Unit C, the students would have topic quizzes from Unit C, unit quizzes from Unit B, and cross-unit quizzes from Units A and B. In general, the instructor tried to spread out the quizzes over the semester so that there were no more than three or four quizzes assigned each lecture period, all due in one week.

Consistent with gameful learning, course grade assignment was based on a cumulative point system, with a total of 1220 points for the course and 150 points between grade cut-offs (e.g., 900 points

resulted in the B/C cutoff and 1050 was the A/B cutoff). However, the passing grade was set such that if students completed all topic and unit quizzes, with 100% success on topic quizzes and partial credit on unit quizzes if 100% wasn't achieved by the third attempt, they would essentially pass the class by attaining a D. Once all topic and unit quizzes were completed, students could "earn up" and increase their grade by completing cross-unit and cumulative quizzes. By implementing this point system, the instructional team rewarded those who struggled to grasp more difficult topics, but also allowed those capable of more complex integration to complete cross-unit and cumulative quizzes to advance in the curriculum. Nearly all students chose to progress past the minimal requirements for passing the course.

Individualized Quiz Construction

The Canvas learning management system provides some tools for constructing individualized assessments. For instance, Canvas allows the creation of a question bank from which a set number of questions can be randomly pulled for each student's quiz. For calculation questions, the platform allows variables with specific ranges and formulas for answer calculations to be entered. The system will then generate questions within specific ranges of variables, again, providing each student with a unique quiz on each topic. Finally, for multiple choice questions, the answers can be randomized so that, even though all the selections are identical from quiz to quiz, the order of answer choices will be unique.

For the course discussed here, an expanded process for quiz generation was needed, and customized spreadsheets were developed (Burns et al. 2022). Briefly, the spreadsheets generate multiple quiz questions (i.e., either True/False, Multiple Choice, Fill in the Blank, or Calculation) using a limited amount of input information, and then produce a markdown text file that can be fed into text2qti (Python program available on GitHub) to generate a quiz and test interoperability (QTI) .zip file. This file contains the questions for the quizzes in a format that can be loaded into Canvas and other quizzing applications. By using these spreadsheets, the instructional team could create different versions of multiple choice questions and calculation questions, allowing for more extensive individualized quizzes. The spreadsheets are included in the appendix of this paper.

While functional, the combined use of spreadsheets, markdown files, and Python code was quite cumbersome. Through a collaboration with CAEN, (Michigan Engineering's information technology department), the authors have now developed a more powerful and versatile program: MiQuizMaker. The program provides a web-based user interface to enter questions and generate the QTI file for loading into Canvas and other similar programs. The quizzes can be constructed with any number of T/F, Multiple Choice, Fill in the Blank, Calculation or File Upload questions, and a preview allows the instructor to view the resulting finished quiz. MiQuizMaker is currently able to be used by anyone with a valid University of Michigan email address and login credentials, and efforts are underway to make MiQuizMaker available to select external users, with the hope

of eventually sharing it with the broader public. For the latest developments on MiQuizMaker, visit https://miquizmaker.engin.umich.edu/.

Although creating and loading individualized assignments into Canvas requires significant time and effort, the process has several benefits, including the elimination of tedious grading of homework and exams. Moore's manual mastery grading system in a thermodynamics engineering class, for instance, required 62% more time than traditional grading approaches, underscoring the value of technological solutions even as they require time and expertise to develop (2016). In addition, creating assignments that can be repeatedly attempted until the desired score is achieved reduces students' incentive to cheat, and the immediately supplied correct answers help students to better understand where they went wrong with their previous attempts.

RESULTS AND DISCUSSION

Sources of Data

The fluid mechanics instructional team collected and analyzed various forms of data from students. At the end of the Winter 2021 term, students completed Michigan Engineering's course evaluation surveys, which collected both quantitative and qualitative data using standard college wide questions and course-specific questions customized by the instructor. The response rate was 57 out of 101 students. The evaluation form included median numerical ratings at the college and university-wide levels, which offered some comparative perspective. To analyze the qualitative data, we thematically coded students' responses and counted the number of times that a particular topic or sentiment appeared. Note that all evaluation responses are supplied in Appendix A, as well as the closed and open-ended questions. We also compared ChE 341 final grades from 2008, when the faculty instructor last taught this class, with those of Winter 2021. However, numerous variables between the two classroom contexts, separated by over a decade and including the unique disruptions of the pandemic, prevented a comprehensive comparative study. To investigate the same students' longer-term perceptions of the course and their learning, the instructional team administered a survey six months later (Fall 2021), when ChE 341 students had progressed to the follow-on ChE 343 engineering course in separation processes. This subsequent survey, completed by 64 of the potential 101 respondents, invited prioritization of elements of the quiz assessment strategy and posed new questions about the different learning modalities. Finally, using data from Canvas (the online course and quiz distribution platform), we examined trends in students' use of the assessment tools. These varied forms of data have surfaced several preliminary findings, with further studies needed to understand the relative weight of each of the pedagogical approaches underpinning ChE 341 and the generalizability of the overall approach for other engineering courses and instructors.

Scaffolding and Immediate Feedback

The first significant finding was that the division of course content into discrete topics, followed by immediate feedback on quizzes, was appreciated by the students. In the open response section of the course evaluation, students could identify ways that the course enabled their learning and recommend the continuation of specific teaching strategies. One student wrote, "*The categorization of topics made it very easy to follow along and understand the flow of the course*," while another noted, "*The slide decks that are separated by topic make the content a lot easier to digest and refer back to.*" Still another respondent emphasized the value of dividing the content into manageable pieces for frequent assessments: *"Looking back I spent a typical amount of time on this course compared to others, but in the moment, the nature of the quizzes allowed me to break it down into small chunks which made it seem like it was so much lighter workload."*

Students additionally remarked on the benefits of increasingly difficult, scaffolded quizzes. One shared, "*I liked the quizzes for the assignments and the segregated topics that built off of each other the later you went on*," while another wrote, "*I think that the quiz format should continue, especially with the different 'levels' of difficulty for the problems*." A third respondent indicated, "*The mini quizzes after each subunit and larger quizzes at the end of the whole unit really helped solidify my understanding of the content being taught*." Ultimately, the cumulative quizzes were designed to pose the greatest challenge of all by requiring students to make connections across several units with fewer possible attempts and no feedback. Consequently, as demonstrated in Figure 2, average grades on cumulative

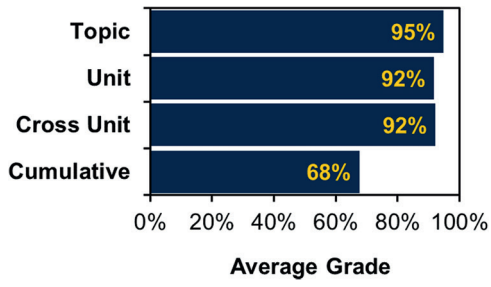

Figure 2. The average grades of each type of quiz. Cumulative quizzes had considerably lower grades than the other quizzes, which is likely due to fewer attempts, no feedback and the increased difficulty of the material being assessed. Alternatively, students may have reached their desired grades near the end of the class and had less impetus to perform well on the cumulative quizzes, with a small fraction of students foregoing the cumulative quizzes altogether. Note that if the incomplete cumulative quizzes are not factored in as zeroes, the average grade for cumulative quizzes is 90%.

quizzes were lower than on the other types of quizzes. However, these rigorous cumulative quizzes were simply one of many measures of students' understandings rather than being a "make or break" experience in the class. Strikingly, there were no failures for the course in Winter 2021, in contrast to the 3.5% of students receiving failing grades in the 2008 version of the ChE 341 course. We will provide further analysis of students' final grades in the closing section of the paper.

Students specifically associated multiple attempts and instant feedback on their quizzes with enhanced learning. Canvas data showed the average number of attempts exceeded 1.67 in all quiz types, which denotes students' widespread use of multiple attempts for formative assessments or non-penalized opportunities to test their understanding. In the survey administered during the follow-on course one semester later, students rated "receiving immediate feedback on quizzes (i.e., the answers)" and "having unlimited/multiple attempts for each quiz" more highly than other characteristics of the quizzing strategy, on average assigning it a 4.8 out of 5 in terms of usefulness. One respondent pragmatically described the benefits of prompt feedback: "*I did not waste so much time wondering if my solution was correct or not on examinations [in this class]. I could try it, see if it worked, and if not, revisit my work and determine what the problem was. Contrastingly, for my other classes, my answers are mere guesses – I submit, pray for the best, and rarely look back at an answer key. This class/format incentivizes me to learn what my mistake is and why, which is arguably the most important part of learning*." Telling is the student's contrast with other classes, where an answer key is usually delayed and cannot provide a timely educational opportunity in sync with students' motivation levels. Because even the most diligent instructors can't sit side-by-side with each of their students simultaneously, using technology to provide feedback at the very moment a student struggles to complete a problem appears to be beneficial for prompt corrective instruction.

Maximizing Students' Choice and Ownership

Another significant finding was the importance of maximizing students' choice and ownership in the learning process, an expression of universally-designed and gameful learning. Data from the Fall 2021 follow-on survey revealed that students appreciated the multi-modal teaching materials. Students valued synchronous activities such as the instructor's worked-out example problems during live lectures, which suggests the enduring importance of direct, human interaction with the teacher in an online classroom. As Figure 3 demonstrates, apart from the lectures, students indicated that they relied most heavily on the various forms of the PowerPoint slides. Notably, the textbooks received the lowest ratings in terms of frequency of use and overall perceived usefulness, which has prompted the faculty instructor to merely recommend but not require the text in future semesters. All modalities received at least moderate rankings from students, which implies that the breadth of choice among instructional resources was advantageous. The multiple teaching modalities also

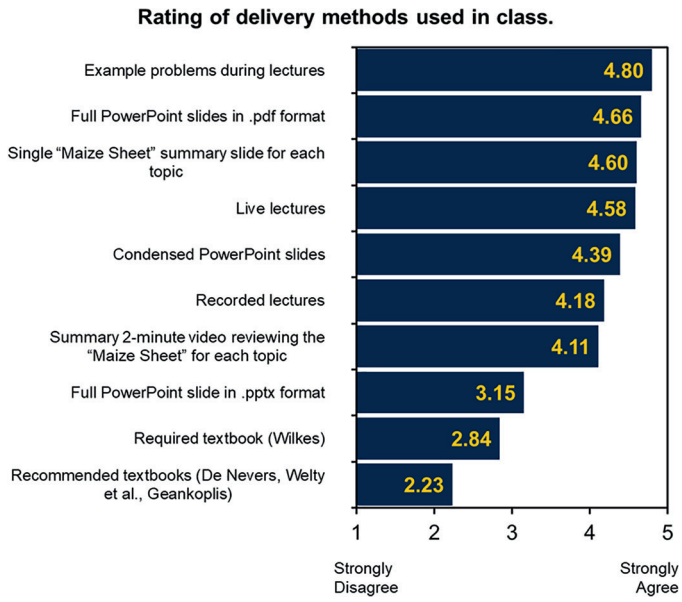

Figure 3. Student ratings of the positive effects of various teaching delivery methods used in class. Ratings ranged from 1 to 5, where: 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree.

catered to different types of learners, whose learning style may have been supplemented with auditory, visual, or kinesthetic materials.

Students also benefitted from having choice and autonomy over the speed of their learning and the timing of their assessments. For many college students, increased academic and social pressures and responsibilities raise stress levels (Ross et al. 1999), all the more so during the pandemic (Clabaugh et al. 2021). But as one student put it, *"The new quiz system implemented was amazing. It allowed me to work on problems at my own pace when it was most convenient, and then also allowed me to learn from previous mistakes and correct myself to achieve the proper solutions."* Another wrote of how flexibly timed assessments diminished anxiety: *"With all my other classes having strict deadlines, it took some stress off of me knowing that I had at least one class that would be a bit more forgiving and understanding, that I'm only human."* To further investigate students' decisions about pacing their learning and scheduling their assessments, we examined Canvas data on the timing of their quiz submissions. Figure 4 reveals that students tended to complete topic quizzes soon after they were posted, which the instructional team typically accomplished immediately after the related lectures. Most students submitted the topic quiz within two days of being introduced to the new content, while their understandings were still fresh. However, the unit quizzes were submitted closer

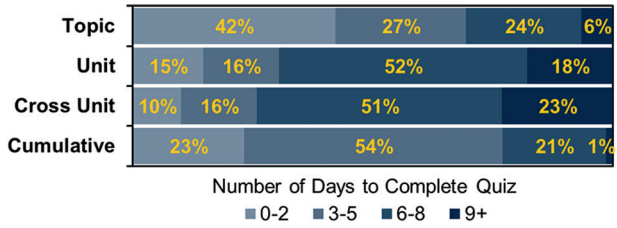

Figure 4. The average number of days students took to complete each quiz by category. The number of days is relative to the date each quiz was posted to the students. Topic quizzes were expected to be completed within two days of release but were accessible for one week. Quizzes released in April (the last month of class) were allowed to be completed any time before May; hence, some quizzes were completed in 9+ days.

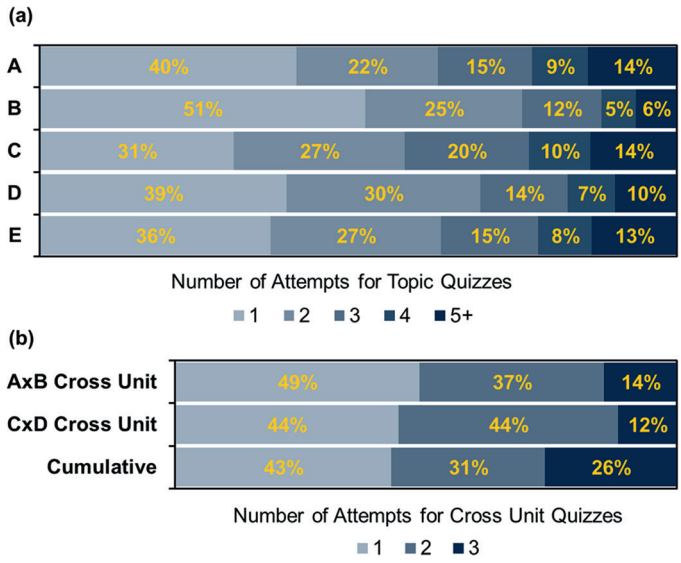

Figure 5. (a) Proportion of the average number of attempts taken for single topic quizzes categorized by unit. Most students used multiple attempts on single topic quizzes, except for unit B quizzes. (b) Proportion of the average number of attempts used by students to complete cross unit quizzes, which had a maximum allowance of three attempts. Again, most students used multiple attempts, though many completed the quizzes in a single attempt.

to the deadlines, with a peak of submission activity occurring over 5 days after the release date. Understandably, students used more time for quizzes requiring the integration of concepts within and across units. Additionally, in the last month of the course, the instructional team struggled to develop and post the quizzes promptly after class sessions, many of which were the C and D unit and cross unit quizzes. To accommodate the backlog of quizzes and the stress of other course finals, the instructor made all remaining quizzes available until the end of the month, which resulted in unit and cross unit quizzes having a large percentage of takers over 9 days after the release date.

Students capitalized on using the quizzes as formative assessments, exercising control over the number of attempts. As one student explained, "*On an exam you tend to memorize a bunch of info and then forget it after the test. However, with the quizzes you can keep testing yourself on every single subject over and over until you get it right and understand the material*." Another concurred, writing, "*The number of quizzes given also gave plenty of practice and repeated exposure so that I feel I have a strong grasp of the material*." While most students only made one or two attempts on the topic quizzes, students practiced more frequently on harder units, indicated by the varied distribution of quiz attempts across the five units. Figure 5-a indicates that Unit B was the easiest for students, as many students only used one attempt. Unit C appears to be the hardest for students, as many students used greater than five attempts. Meanwhile, Figure 5-b indicates that cross-unit quizzes increased in difficulty over the course of the semester. Almost twice as many students used three attempts on the cumulative quizzes compared to the other cross-unit quizzes.

More Freedom to Fail, Less Stress in Learning

An additional significant finding is that the course's mastery-based, gameful learning design gave students the freedom to fail, ultimately enabling deeper understanding and reducing their stress levels. While an attainable level of challenge can produce educational gains, Vogel and Schwabe demonstrate that stress in educational settings creates a memory retrieval deficit, prompting rigid memories rather than flexible cognitive forms of learning that allow for integration of new information. These findings, which emerge among learners of all ages, suggest that memories of poor exam performances can lastingly hinder students' subsequent academic work and limit their ability to assimilate new information into existing knowledge structures (2016). Accordingly, the ChE 341 instructional team was pleased that, in the final ChE 341 course evaluations, numerous students linked multiple assessment attempts with opportunities for instructive, safe mistakes. One student responded, "*The class does not 'punish' students for making a calculation error in the quizzes or for not understanding a specific part of the material since you have a minimum three attempts for all quizzes*." In keeping with research on the benefits of low- stakes assessments (Meer and Chapman 2014), others tied the availability of

multiple attempts to the normalization of momentary failure, a diminished sense of risk in the learning process, and enhanced learning and motivation. Expressing a preference for frequent quizzes over the periodic submission of larger homework sets, another student wrote, "*I actually had the incentive to see where I went wrong and work backwards, instead of getting one chance, being upset with trying and getting partial credit, and then never looking at the problem again because of frustration and knowing the grade won't change*."

Overwhelmingly, students spoke of reduced stress in this class because of the substitution of quizzes for high-stakes assessments in measuring students' learning and determination of course grades. One student's feedback effectively captured the benefits cited by the broader class: "*I wish more classes implemented this [quizzing strategy] as well. It was a lot less stressful not having to worry about studying for any big midterms or finals, and I feel like I learned a lot more in this class than I would have because of the way this class was paced and taught*." Correspondingly, in the quantitative portion of the final course evaluations, the statement "Multiple quiz format reduced my stress in this course" received a 4.9 out of 5 rating, with no median comparison available for other classes due to the question's uniqueness. In the course evaluations, some students voiced concern that the workload felt disproportionately heavier toward the end of the semester because there was an increased number of quizzes at that point, and the instructional team struggled to develop and post the quizzes promptly after class sessions. Such feedback has since prompted the instructional team to reconsider the pacing of the course to evenly distribute the intensity across the semester. Yet these concerns appeared not to outweigh the overall appreciation for the frequent formative assessments.

Strengthened Equity, Integrity, and Climate

With Michigan Engineering's commitment to equity-centered engineering, the final, highly encouraging finding was that the reworked ChE 341 course strengthened equity in the class and led to other psychosocial benefits. As reflected in the appended course evaluations, one student noted that being able to switch between synchronous and asynchronous classes enabled completion of the class around the demands of a job. Another generally credited the course's unique design as conducive for accommodating learning disabilities, while a third expressed gratitude for how flexibly scheduled assessments supported more success for students who are medically challenged. A fourth student acknowledged, "*As a woman in STEM, one of my biggest weaknesses is lacking a voice. I've been talked over many times, and rarely have confidence in my answers/solutions. However, with this format, since I know I'm doing a problem right (or wrong), I have so much more confidence to help others/give advice . . . I wish more of my courses were like this*." Such responses become weightier given that the open response portion of the course evaluation did not directly invite feedback on matters of equity and inclusion.

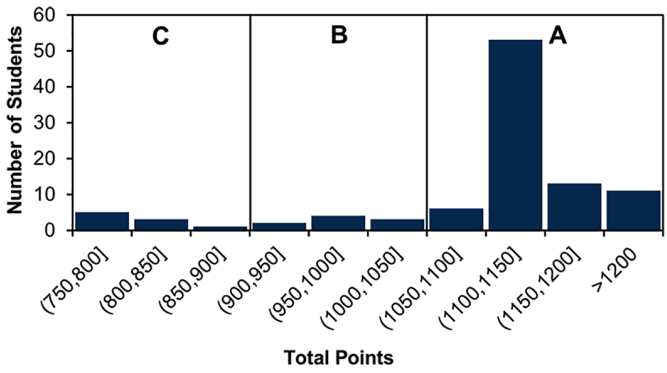

Figure 6. Average grade distribution based on points acquired by the end of the class. The cutoffs for each letter grade were C = (750–900], B = (900–1050], and A = 1050+.

Further evidence of the course's support for equity-centered engineering instruction comes from data on final course grades. The revised ChE 341 course was intentionally constructed so that any student who completed all of the topic and unit quizzes would pass the course. But in keeping with the "earning up" model in gameful learning, students could earn additional points through the cross-unit and cumulative quizzes. Ultimately, in the 2021 version of the class, approximately 80% of the students received "A" grades by earning at least 1050 of a potential 1220 points (See Figure 6). Note that, although the form of class assessment was different, the instructor used similar questions in this class to the ones he used on the homework and exam problems in previous years. That so many students achieved an "A" grade points to the course's promotion of success for all students if they were willing to put in the work. In Perez and Verdin's review of mastery learning in undergraduate engineering courses, we likewise see that mastery learning generally results in higher grades on exams and homework assignments (2022). As noted in the National Academies study of barriers and opportunities for STEM degrees, "academic climates that emphasize learning, mastery, and improvement in math and science, rather than inherent ability" enhance students' beliefs in their abilities to succeed, which strengthen performance and persistence—perhaps especially so for historically underrepresented groups (2016). In short, we should not be surprised or concerned that a modified mastery learning strategy closed achievement gaps, but recognize its potential to motivate extended effort and deeper learning for higher numbers of students.

Additional higher education literature further dispels concerns about potential grade inflation in ChE 341. Bowen and Cooper (2022) launch nine different critiques of the historical dependence on bell curves for assigning grades, noting that the practice serves more as a sorting mechanism than a reliable means of evaluating learning and contending that most scholars today recognize its flaws. Even as O'Halloran and Gordon (2014) rightly pursue a meaningful use of grades and rigorous instruction,

they acknowledge that the topic of grade inflation itself remains controversial. They define grade inflation as an upward trend in grade distribution that correlates with students' disengagement from purposeful learning activities and lack of academic achievement, which seems the very opposite of ChE 341 students' persistence in attempting quizzes multiple times and perceived readiness for the ChE 343 separation processes course when surveyed one semester later.

Another apparent benefit from the course's restructure is strengthened academic integrity. In the customized final course evaluation, students strongly agreed with the statement that the course "diminished the incentive to cheat compared to other courses," rating it 4.9 out of 5. One hypothesis for disincentivized cheating, of course, is that hundreds of variations on the quizzes made it nearly impossible to replicate answers from another student's quiz. However, co-existing factors may include students' heightened perceptions of fairness due to the course's scaffolded design, attainable pathways toward success, and frequent low-stakes assessments, all of which prevented students from experiences of desperation that can inspire cheating. In the Fall 2021 survey, students were asked about the frequency of solving problems backwards, using the provided answer to determine the correct calculation rather than knowing how to correctly solve the problem from the outset. The majority of respondents indicated that they either "somewhat agreed" or "strongly agreed" with the statement, "You often heard of some students, or yourself, back-calculating the answer on a quiz." While this trend may reveal that manipulating the system is possible, even backward calculation enables learning and would only minimally account for students' success on the quizzes. Arguably, this process wouldn't constitute cheating but simply logical inference, functioning as a scaffolded form of learning.

CONCLUSION

In the end, the final course evaluations conveyed students' appreciation for the redesigned class, which they associated with an enjoyable classroom climate. Students' responses often explicitly linked the structure of the course with their sense of the instructor's care and respect for them, noting his commitment to their well-being and marveling at a "*new system*" that "*is truly revolutionary*." The faculty instructor received a 5 out of 5 rating for the statement, "This instructor was an excellent teacher," with a school-wide median of 4.6 and university-wide median of 4.7. As one student put it, "*I appreciate that you've been so considerate during unique circumstances. You've acted in the interest of the students and I respect that*." One of the psychosocial benefits experienced by both the instructional team and the students appears to have been a deeper sense of interpersonal connection, forged in part by camaraderie of engaging in a virtual classroom during a pandemic. Yet the students also clearly experienced the design of the course, from the flexible-time assessments to the opportunities to learn from mistakes, as expressions of the instructor's good will toward them.

Notably, a few students seemed conflicted about whether the class might have been made too accessible for them, even as others indicated that they spent the same amount of effort in this class as others. One student summed up this sentiment: "*It may seem like it just makes everything easier and is not challenging students, but I think I actually learned more without unnecessary stress, so thank you.*" Interestingly, when surveyed during the follow-on separation processes course about the previous ChE 341 learning strategies that they would hope to see implemented in other engineering classes, about one quarter of responding students recommended against replacing all homework and exams with quizzes. Yet within the same survey, the learning strategies that students most frequently prioritized for recommended implementation in future classes were having multiple attempts for quizzes and receiving immediate feedback on quizzes. A few respondents also presumed that the student-centered, mastery-based approach might have been unique to the challenges of the pandemic and not ideally suited for ordinary times. In the course evaluations, one student commented that "*If virtual formats are continued then I would just continue this format with the quizzes and immediate grading. If in-person starts again then I think it would be a good idea to have these quizzes for practice/preparation of upcoming exams.* This sentiment—though rarely expressed among the respondents—may point to an inherent discomfort in moving away from high-stakes assessments and related competitive culture that has long characterized the STEM disciplines (National Academies 2016).

Skepticism around the value of frequent low-stakes assessments can emerge for faculty as well, who may believe it is part of their mission to inflict high levels of stress upon students to equip them for the "real world." The discomfort felt by both students and faculty around departures from high-stakes assessments may be explained, in part, through the psychological phenomenon of effort justification. Namely, many worthwhile endeavors in life require short-term sacrifice or hardship to achieve longer-term gains, such as a college degree or a job promotion, and effort justification emerges when people evaluate an accomplishment more favorably if it involves a difficult or even disagreeable activity. This psychological maneuver can help resolve cognitive dissonance, or the uneasiness in wondering whether the task is truly worth the effort (Rosenfeld et al. 1984).

Ultimately, the preliminary results from the redesigned ChE 341 course suggest that high-stress, high-stakes assessment is not necessary for satisfactory learning. Moreover, the unique combination of instructional strategies used in ChE 341 course may hold promise for other classroom settings, with further understandings to be accomplished through more expansive studies. Admittedly, converting a typical lecture class into this format requires an initially heavy lift, but the most burdensome component—the generation of tens of thousands of unique quizzes—is lightened by using the developed spreadsheets or MiQuizMaker web application. Future improvements and advances in instructional technology will hopefully enhance this blend of established pedagogical strategies and decrease the effort needed by faculty in adapting similar practices.

Ideally, other faculty will experiment with the techniques outlined in this article and report the effects on student learning. Because the bulk of the data was derived from student surveys, adding comparison data from multi-section classrooms and other direct data collection would help elucidate the true impact of this teaching style. For our part, the instructor used many of the same problems from years he taught the class in a traditional manner and found that the students scored better in this new setting, both for exam problems—not surprisingly as the students had more time and a more relaxed environment to obtain the solution—and for homework problems. The improvement from traditional homework results seems to indicate the advantage of this technique as the settings and time periods are comparable. The instructor has continued to teach the course using these techniques in an in-person setting, and the results from the students have been very positive.

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REFERENCES

Ajlen, Ronit, Benjamin Plummer, Evan Straub, and Erping Zhu. 2020. "Motivating Students to Learn: Transforming Courses Using a Gameful Approach." CRLT Occasional Paper No. 40. Ann Arbor, MI: Center for Research on Learning and Teaching. https://crlt.umich.edu/sites/default/files/resource_files/CRLT_no40.pdf.

American Society for Engineering Education. 2016. *Engineering by the Numbers: ASEE Retention and Time-to-Graduation Benchmarks for Undergraduate Engineering Schools, Departments and Programs*. Washington, DC: Brian L. Yoder.

Armacost, Robert L., and Julia Pet-Armacost. 2003. "Using Mastery-Based Grading to Facilitate Learning." In *33rd Annual Frontiers in Education Conference Proceedings,* Vol. 1, T3A-20. Westminster, CO: IEEE. https://doi.org/10.1109/FIE.2003.1263320.

Bekki, Jennifer M., Odesma Dalrymple, and Caitlyn S. Butler. 2012. "A Mastery-based Learning Approach for Undergraduate Engineering Programs." In *Frontiers in Education Conference Proceedings*, 1–6. https://doi.org/10.1109/FIE.2012.6462253.

Bloom, Benjamin S. 1973. "Recent Developments in Mastery Learning." *Educational Psychologist* 10 (2): 53–57. https://doi.org/10.1080/00461527309529091.

Bowen, Ryan S., and Melanie M. Cooper. 2022. "Grading on a Curve as a Systemic Issue of Equity in Chemistry Education." *Journal of Chemical Education* 99 (1): 185–194. https://doi.org/10.1021/acs.jchemed.1c00369.

Brito, Claudio R., Melany M. Ciampi, James J. Sluss, and Henrique D. Santos. 2019. "Trends in Engineering Education: a Disruptive View for Not So Far Future." In *18th International Conference on Information Technology Based Higher Education and Training (ITHET)*, 1–5. IEEE. https://doi:10.1109/ITHET46829.2019.8937349.

Burns, Mark, Valerie Johnson, and Kaylee Smith. 2022. "Unique and Randomized Quiz Generation for Enhanced Learning." In *2022 ASEE Annual Conference & Exposition*. https://peer.asee.org/unique-and-randomized-quiz-generation-for-enhanced-learning.

Chen, John, Renee Clark, and Gary Lichtenstein. 2020. "Overview–Special Issue on COVID-19." *Advances in Engineering Education* 8 (4): 1–7. https://advances.asee.org/wp-content/uploads/Covid%2019%20Issue/Text/AEE-COVID-19-From_the_Editors.pdf.

Clabaugh, Alison, Juan F. Duque, and Logan J. Fields. 2021. "Academic Stress and Emotional Well-being in United States College Students Following Onset of the COVID-19 Pandemic." *Frontiers in Psychology* 12: 628787. https://doi.org/10.3389/fpsyg.2021.628787.

Dennen, Vanessa P. 2007. "Cognitive Apprenticeship in Educational Practice: Research on Scaffolding, Modeling, Mentoring, and Coaching as Instructional Strategies." In *Handbook of Research on Educational Communications and Technology*, edited by J. Michael Spector, M. David Merrill, Jeroen van Merrienboer, Marcy P. Driscoll, 804-819. 3rd ed. Abingdon: Routledge. https://doi.org/10.4324/9780203880869.

Felder, Richard M., Rebecca Brent, and Michael J. Prince. 2011. "Engineering Instructional Development: Programs, Best Practices, and Recommendations." *Journal of Engineering Education* 100 (1): 89–122. https://doi.org/10.1002/j.2168-9830.2011.tb00005.x.

Fishman, Barry, and Caitlin Hayward. 2022. "Gameful Learning: Leveraging the Learning Sciences to Improve the Game of Learning." Rapid Community Report Series. Digital Promise and the International Society of the Learning Sciences. https://repository.isls.org//handle/1/7663.

Freeman, Scott, Sarah L. Eddy, Miles McDonough, Michelle K. Smith, Nnadozie Okoroafor, Hannah Jordt, and Mary Pat Wenderoth. 2014. "Active Learning Increases Student Performance in Science, Engineering, and Mathematics." *Proceedings of the National Academy of Sciences* 111 (23): 8410–8415. https://doi.org/10.1073/pnas.1319030111.

Green, Roger. 2000. "Mastery Learning with the MATLAB Webserver." In *2000 ASEE Annual Conference Proceedings*, 5–440. https://doi.org/10.18260/1-2--8551.

Halls, Jonathan G., Carmen Tomás, John S. Owen, and Kamel Hawwash. 2022. "Mapping Out the Landscape of Literature on Assessment in Engineering Education." *European Journal of Engineering Education* 4 (3: 373–393. https://doi.org/10.1080/03043797.2021.2009775.

Knight, Peter T. 2002. "Summative Assessment in Higher Education: Practices in Disarray." *Studies in Higher Education* 27 (3): 275–286. https://doi.org/10.1080/03075070220000662.

Kress, Gunther and Theo van Leeuwen. 2001. Multimodal Discourse: The Modes and Media of Contemporary Communication. Oxford UK: Oxford University Press.

McCallum, Suzanne, and Margaret M. Milner. 2021. "The Effectiveness of Formative Assessment: Student Views and Staff Reflections." *Assessment & Evaluation in Higher Education* 46 (1): 1–16. https://doi.org/10.1080/02602938.2020.1754761.

Meer, Nicky M., and Amanda Chapman. 2014. "Assessment for Confidence: Exploring the Impact that Low-stakes Assessment Design Has on Student Retention." *The International Journal of Management Education* 12 (2): 186–192. https://doi.org/10.1016/j.ijme.2014.01.003.

Moore, Jacob. 2016. "Mastery Grading of Engineering Homework Assignments." In *2016 IEEE Frontiers in Education Conference (FIE)*1–9. IEEE. https://doi.org/10.1109/FIE.2016.7757584.

National Academies of Sciences, Engineering, and Medicine. 2016. *Barriers and Opportunities for 2-year and 4-year STEM Degrees: Systemic Change to Support Students' Diverse Pathways*. Washington, D.C.: National Academies Press. https://doi.org/10.17226/21739.

Olds, Barbara M., Barbara M. Moskal, and Ronald L. Miller. 2005. "Assessment in Engineering Education: Evolution, Approaches and Future Collaborations." *Journal of Engineering Education* 94 (1): 13–25. https://doi.org/10.1002/j.2168-9830.2005.tb00826.x.

Perez, Carlos, and Dina Verdin. 2022. "Mastery Learning in Undergraduate Engineering Courses: A Systematic Review." In *2022 ASEE Annual Conference & Exposition*.

Qadir, Junaid, Abd-Elhamid M. Taha, Kok-Lim Alvin Yau, Joao Ponciano, Sajjad Hussain, Ala Al-Fuqaha, and Muhammad Ali Imran. 2020. "Leveraging the Force of Formative Assessment & Feedback for Effective Engineering Education." In *2020 ASEE Annual Conference & Exposition*. https://doi.org/10.18260/1-2--34923.

Rogers-Shaw, Carol, Davin J. Carr-Chellman, and Jinhee Choi. 2018. "Universal Design for Learning: Guidelines for Accessible Online Instruction." *Adult Learning* 29 (1): 20–31. https://doi.org/10.1177/1045159517735530.

Rosenfeld, Paul, Robert A. Giacalone, and James T. Tedeschi. 1984. "Cognitive Dissonance and Impression Management Explanations for Effort Justification." *Personality and Social Psychology Bulletin* 10 (3): 394–401. https://doi.org/10.1177/0146167284103007.

Ross, Shannon E., Bradley C. Niebling, and Teresa M. Heckert. 1999. "Sources of Stress Among College Students." *College Student Journal* 33 (2) : 312. *Gale Academic OneFile*. https://link.gale.com/apps/doc/A62839434/AONE?u=anon-f4db7849&sid=googleScholar&xid=0c236077.

Rust, Chris. 2007. "Towards a Scholarship of Assessment." *Assessment & Evaluation in Higher Education* 32 (2): 229–237. https://doi.org/10.1080/02602930600805192.

Sangelkar, Shraddha, Omar M. Ashour, Russell L. Warley, and Oladipo Onipede. 2014. "Mastery Learning in Engineering: A Case Study in Statics." In *2014 ASEE Annual Conference & Exposition*, 24–887. https://doi.org/10.18260/1-2--22820.

Vogel, Susanne, and Lars Schwabe. 2016. "Learning and Memory under Stress: Implications for the Classroom." *npj Science of Learning* 1 (1): 1–10. https://www.nature.com/articles/npjscilearn201611.

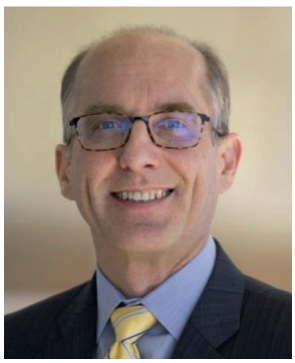
Walker, Erica, John DesJardins, and Bre Przestrzelski. 2020. "Re-Designing the Senior Design Classroom Experience with Game-Based Learning." *Advances in Engineering Education*. https://eric.ed.gov/?id=EJ1255252.

Wallwey, Cassie, Giselle Guanes, Jeremy Grifski, and Tyler Milburn. 2022. "Engineering and Exclusionary 'Weed-Out' Culture: A Framework for Exploring Literature for Meaning and Influence." In *2022 ASEE Annual Conference & Exposition*.

Wilkes, James O., and Stacy G. Birmingham. *Fluid Mechanics for Chemical Engineers with Microfluidics and CFD*. Pearson Education, 2006.

Yorke, Mantz. 2011. "Summative Assessment: Dealing with the 'Measurement Fallacy." *Studies in Higher Education* 36 (3): 251–273. https://doi.org/10.1080/03075070903545082.

AUTHORS



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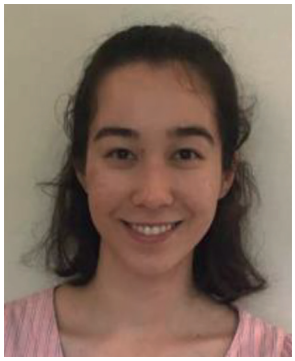

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APPENDIX

University of Michigan

Winter 2021 Instructor Report With Comments

CHE 341-001: Fluid Mechanics

Mark Burns

57 out of 101 students responded to this evaluation.

Responses to University-wide questions about the course

	SA	A	N	D	SD	N/A	Your Median	Univ-wide Median	School/College Median
This course advanced my understanding of the subject matter. (Q1631)	43	11	0	0	0	0	4.9	4.6	4.4
My interest in the subject has increased because of this course. (Q1632)	29	20	7	0	0	0	4.5	4.3	4.1
I knew what was expected of me in this course. (Q1633)	50	6	0	0	0	0	4.9	4.6	4.2
Overall, this was an excellent course. (Q1)	48	8	0	0	0	0	4.9	4.4	4.1
I had a strong desire to take this course. (Q4)	12	17	19	4	2	1	3.6	4.1	3.9
As compared with other courses of equal credit, the workload for this course was (SA=Much Lighter, A=Lighter, N=Typical, D=Heavier, SD=Much Heavier). (Q891)	0	12	36	6	2	0	3.1	2.9	2.8
How did you participate in this course? (SA=Attended most synchronously, A=Attended most asynchronously, N=Attended most in person, D=Attended some in person and some online) (Q1854)	41	14	0	0	0	1	4.8	4.8	4.4

Responses to University-wide questions about the instructor

	SA	A	N	D	SD	N/A	Your Median	Univ-wide Median	School/College Median
Overall, Mark Burns was an excellent teacher. (Q2)	53	2	1	0	0	0	5.0	4.7	4.6
Mark Burns seemed well prepared for class meetings. (Q230)	44	12	0	0	0	0	4.9	4.8	4.7
Mark Burns explained material clearly. (Q199)	45	11	0	0	0	0	4.9	4.7	4.6
Mark Burns treated students with respect. (Q217)	54	1	1	0	0	0	5.0	4.9	4.7

Responses to questions about the course

	SA	A	N	D	SD	N/A	Your Median	University-Wide Median
I increased my ability to formulate, and solve engineering problems. (Q23)	44	11	1	0	0	0	4.9	4.4
The textbook made a valuable contribution to the course. (Q64)	8	21	19	8	0	0	3.5	3.8
Work requirements and grading system were clear from the beginning. (Q232)	44	11	1	0	0	0	4.9	4.7
The textbook was easy to read and understand. (Q341)	11	15	19	8	0	2	3.5	4.1
Examinations covered the important aspects of the course. (Q356)	35	9	2	0	0	10	4.8	4.5
Exams were reasonable in length and difficulty. (Q360)	34	9	2	0	0	11	4.8	4.2

Responses to questions about the instructor

	SA	A	N	D	SD	N/A	Your Median	University-Wide Median
Mark Burns stressed important points in lectures/discussions. (Q203)	45	9	2	0	0	0	4.9	4.7
Mark Burns put material across in an interesting way. (Q205)	44	11	1	0	0	0	4.9	4.6
Mark Burns acknowledged all questions insofar as possible. Q216)	48	8	0	0	0	0	4.9	4.8
Mark Burns used class time well. (Q229)	48	8	0	0	0	0	4.9	4.7

The quiz format and immediate grading increased my ability to learn the material. (custom question added by the instructor)

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	N/A	Your Median
50	5	1	0	0	0	4.9

The multiple quiz format instead of several tests and a final reduced my stress in this course. (custom question added by the instructor)

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	N/A	Your Median
50	5	2	0	0	0	4.9

The quiz format reduced the incentive and amount of cheating in the course compared to other courses. (custom question added by the instructor)

Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	N/A	Your Median
50	8	1	0	0	2	4.9

The medians are calculated from Winter 2021 data. University-wide medians are based on all UM classes in which an item was used. The school/college medians in this report are based on classes that are upper division with enrollment of 75 or greater in College of Engineering.

Written Comments

How did the teaching techniques (e.g., certain technologies used, specific approaches to testing and assignments, asynchronous or synchronous teaching methods, instructor flexibility, class interaction, small group work, other teaching methods) of this course serve the aims of this course/or serve your learning in this course? (Q1872)

Comments
The approach to this class was completely different from any other I have taken before, which made me nervous at first, but so far has been super helpful. For someone like me that has some learning disabilities this format has allowed me to learn more than I have in any other class.
I really enjoyed the teaching techniques used in this course. The use of the quizzes was really helpful. I also appreciated the spreadsheet posted to keep track of points. The use of the quizzes with multiple attempts.
I enjoyed working on quizzes in my own time and having to complete one for each topic to make sure I understood every single topic. The material was well presented and I could still ask for help on approaches to different quizzes if I was having trouble.
Out of the three coursed I had this semester, this one performed well beyond the rest. The lectures were clear and understandable and the other content, such as Sunday reviews and Recitations were the butter on a already well frosted cake.
I loved working out examples when we got the Unit D. That really was the most effective way to practice NS simplifications.
The quiz system made taking this class online much less stressful.
Discussions were very helpful in cementing material from lecture.
The slide format is excellent, and the derivations help to enforce the material.
I liked that this course used canvas quizzes instead of actual exams because it made learning the material through mistakes more acceptable and decreased my stress.
I loved how Professor Burns really emphasized the material we needed to know, he didn't waste time on intro stuff that took the whole time and the slides that he presented with had all the necessary information to succeed in this class.
Teaching techniques were good. I am glad that he allowed multiple attempts for some quizzes so that we could learn from our mistakes. Also, using examples for most of the sections was good.
The setup of quizzes were pretty nice.
I liked how the derivation of each formula used in the class was shown. I also really enjoyed the format of the assessments. I believe completing small quizzes after each lecture as well as combined quizzes really helped me grasp the concepts of the course, and it ensured I was remembering all of the important information learned throughout the semester.
Small low stake assignments helped make learning the material much more interesting and less stressful.
I absolutely loved the continuous assessments through canvas quizzes – using this assessment approach instead of a few heavily weighted quizzes or exams made the environment much less stressful, and the multiple attempts on quizzes really allowed me to retain the lecture material easier and practice applying it to real–world problems we'd face as engineers. I also loved the maize pages and review slides we were given after the completion of larger units.

The multiple quizzes enhanced my learning so much for this course because I was able to internalize a lot of the information a lot more because we were going topic by topic.
I loved the flexibility of this course. The quizzes as opposed to midterms/final exams was incredibly stress relieving and seemed to help me learn even better. On an exam you tend to memorize a bunch of info and then forget it after the test. However, with the quizzes you can keep testing yourself on every single subject over and over until you get it right and understand the material. Less stress and better understanding!
Synchronous classes, but recorded for those who couldn't make it helped me complete the class around my work schedule.
The instructor is extremely responsive to student feedback and constantly asks students if clarification is needed on topics. The slide decks that are separated by topic make the content a lot easier to digest and refer back to. The topic quizzes also make learning and making mistakes seem more risk free due to the unlimited attempts.
I really enjoyed having synchronous lectures, that the lecture slides were already typed out and that Professor Burns went step by step with them, doing worked out example problems and that he was very receptive to our feedback and needs.
The Canvas Quizzes with immediate feedback and a correct answer shown gave me a chance to correct any errors in my understanding of the material. The number of quizzes given also gave plenty of practice and repeated exposure so that I feel I have a strong grasp of the material.
I really really liked the canvas quiz format instead of midterms and a final. It took so much stress off from the class, especially since I had been told its one of the hardest semesters as a ChE.
The slide decks for each unit were very well organized and easy to understand. The approach to assignments in this class was different that what I was used to but I think the mini quizzes were an excellent form of mastery assessment and I hope it continues in the future. The DEI modules were also very interesting and I was able to learn a lot from them.
Helped me better learn the material, lowered the stress.
I liked the derivations we did in class and the explanations of how each variables interact and effect each other.
The quizzes were a nice change from the typical homework/exams; they reduced pressure a bit, and they helped reinforce material AS we were learning it.
Well.
Descriptive visuals and clean slides really helped me learn complicated course concepts.
Having all class work in quiz format really helped my learning. It was reassuring to know that I had multiple tries on the quizzes, which ensured that I learned from my mistakes and actually understood the material. I also liked having the videos that were summaries of what we learned (the Maize Summaries). This was.
The Canvas quizzes were used effectively.
The quizzes decreased by stress level significantly while increasing my understanding of the material and the equations and how to use them. Professor Burns created a classroom environment that was fun and made me enjoy going to class through making jokes and smiling. I really enjoyed going through the derivations because I feel like I have a complete handle on how to simplify really complicated equations now.
Prof. Burns taught the material very well that was required to know for the assignments.
The new quiz system implemented was amazing. It allowed me to work on problems at my own pace when it was most convenient, and then also allowed me to learn from previous mistakes and correct myself to achieve the proper solutions.
The unlimited number of quizzes let me go over my mistake in the solving steps and made me think what concepts I was confused on. The cumulative quizzes helped me see the connections across the units.
The asynchronous quizzes decreased stress levels.
The new structure used in this course was incredibly beneficial, the material was incredibly well–taught, and the quiz set–up really made the workload manageable, looking back I spent a typical amount of time on this course compared to others, but in the moment the nature of the quizzes allowed me to break it down into small chunks which made it seem like it was so much lighter workload.

Given your experience in this course, what teaching techniques do you think the instructor should continue to use in the future (e.g., certain technologies used, specific approaches to testing and assignments, other testing methods, asynchronous or synchronous teaching methods, instructor flexibility, class interaction, small group work, other teaching methods)? (Q1873)

Comments
The categorization of topics made it very easy to follow along and understand the flow of the course.
I think having unlimited quizzes where we were forced to continue to repeat methods until we got a correct numerical answer taught me more than submitting a problem set at the end of the week with a variety of questions has ever given me. Not only did it decrease stress, but I actually had the incentive to see where I went wrong and work backwards, instead of getting one chance, being upset with trying and getting partial credit, and then never looking at the problem again because of frustration and knowing the grade won't change. It may seem like it just makes everything easier and is not challenging students, but I think I actually learned more without unnecessary stress, so thank you.
I think that the use of quizzes in lieu of regular homework assignments and exams is a great way to pace organize the course. I also found the organization of the lecture material to be very helpful, especially the useful equations and overview on the first slide.
I think the quizzes are beneficial for me to learn. I also enjoyed the implementation of DEI within the course and recognizing that there are issues revolving the work we will do in the future.
I would continue the layout of the course. The quizzes helped me check my learning.
I liked all of the maize sheet summaries. It was really nice having all of the equations I needed in 1 powerpoint especially when I was taking the quizzes.
Quiz format instead of exams.
Keep the derivations and slides.
I think canvas quizzes should still be used in the future even if its just to replace homework assignments.
I definitely think he should continue to use the quiz format. I really loved this class format because it greatly reduced my stress this semester, and it helped me still enjoy the material while learning. I was never uninterested in something he presented on. I wish more of my classes used this style of teaching.
If virtual formats are continued then I would just continue this format with the quizzes and immediate grading. If in–person starts again then I think it would be a good idea to have these quizzes for practice/preparation of upcoming exams.
Keep the unlimited attempt quizzes – those are good.
I believe the course format should remain the same as it is aimed towards remembering the important concepts instead of learning and forgetting topics almost directly after they were taught.
Keep doing small assignments and quizzes because they allow much more flexibility and ease of learning.
Continue using the maize pages and continuous quiz technique.
The multiple quizzes are so nice! I wish every course had them.
The quizzes were a great way to learn and allowed me to be less stressed.
Again, the quiz method should be kept. The only thing I would change about this class is maybe spend less time on derivations and more time on examples related to the quizzes – that's just personally helps me learn I don't really enjoy derivations.
The quiz testing methods helped to take a lot of the stress of the course out. However, the workload felt disproportionately heavier at the ends. It would help to have that spread throughout the semester instead.
I definitely liked the way this course was run and I wish more classes implemented this as well. It was a lot less stressful not having to worry about studying for any big midterms or finals and I feel like I learned a lot more in this class than I would have because of the way this class was paced and taught. Doing quizzes on topics gradually throughout the semester with multiple attempts really helped me understand the material better.
This course was one of the best I have had at the university so far due to the teaching team. They are very willing to work with students and adjust the curriculum accordingly. I think the structure of how the topics are taught should be carried forward to future semesters as well as the topic quizzes. The lack of exams takes the stress out of the course, while the workload from the quizzes keeps students engaged with the content.
Continue synchronous work, with pre filled out slides that with each click show more information, continue doing worked out examples, and continue being a welcoming guy!

Continue releasing the Canvas Quizzes, Summary/Maize sheets, annotated lecture notes.
I think you should continue the canvas quizzes style, but if there is a possibility, spread out them earlier in the semester because having so many quizzes at the end of the semester is a little overwhelming.
I think the instructor should continue this new style of teaching. The mini quizzes after each sub unit and larger quizzes at the end of the whole unit really helped solidify my understanding of the content being taught.
Sunday reviews, maize sheets, the format of the class in regards to quizzes only, immediate grading.
Continue with the quizzes.
However, I felt like the format made the class a bit more time consuming; as someone with 3 other very difficult/time consuming courses, having a 4th course that might have been slightly more time consuming than it should have been meant I was working around the clock. Part of that is my fault, because I was warned my schedule may be too difficult, but here we are at the end, and I've done it. I don't know if I would continue the format in the future, especially in an in person setting. I felt this format was good for remote class, but I'm not too sure about in person. Plus, I know that it sounded like a lot of work for both Prof. Burns and the GSI's to set up all these quizzes, and I thank them for taking all that time to do so.
I enjoyed the lectures, they were engaging. The changes made to make the course better fitted for online education was clearly in the interest of making the students' lives easier — thank you.
EVERYTHING!
I think that the quiz format should continue, especially with the different "levels" of difficulty for the problems.
The Maize sheets were extremely helpful!! I wish more classes would give direct summaries like that.
Everything that I mentioned above, so quizzes, derivations, and creating an enjoyable classroom environment.
I liked the quizzes for the assignments and the segregated topics that built off of each other the later you went on.
Continue the new quiz system. It is truly a wonderful idea.
Current method of giving out quizzes.
You should definitely continue the process equipment readings.

Please enter any additional comments you have for Mark Burns. (Q981)

Comments
I can tell Professor Burns cares about his students and he cares about us learning the material and having a clear understanding of what's going on. He shows this by asking if we have questions frequently and takes his time to explain difficult concepts in lecture.
Thank you for all the effort in making the quizzes. Now that they are generated, it may be easier for the next time around to make them a little more spaced out at the end of the semester.
Thank you for checking in with us so often throughout the semester and always asking for our feedback!
Thank you, Professor Burns! The quiz format was very helpful for reducing our stress surrounding fluids for this unusual semester, and we appreciate the teaching team's effort to accommodate us.
I found that the system of small quizzes was much better for addressing the material and great in reducing the stress. However, I have some concerns related to the format. I do appreciate having the quiz format, but I›m not too sure how the quiz format will transfer to long–term learning.
Also, the implementation of this quiz format needs to be more spread out. The amount of quizzes coming this week and the next two is overwhelming. I know that these quizzes need to be written up and then added, but there are too many quizzes to be dealt with, especially during a time when we should be studying for finals in classes (and the last final quizzes for this class).
However, I found that the instruction of this course was excellent, and the teaching team are very responsive to the needs of the students. That effort is appreciated.
Thank you so much for trying this format, I loved learning this way and I feel like I am coming out of this class knowing the material I need to progress further in CHE. This was by far my favorite class this semester and I seriously can't thank you enough, I hope that more professors pick up this style of teaching!
It's great having you this semester! Thank you!
He was a fantastic professor and I really appreciate his efforts to reduce the mental stress his students had to endure insofar as possible.

I really enjoyed this class. You were a great professor, and I hope to have you for another class in the future!

I loved this course, and I'm excited to study more areas of fluid mechanics in the future. Great thanks to you and all of the GSI's for making this class interesting so we can retain more knowledge for our future careers.

Thank you, Professor Burns! This class has reaffirmed my love for chemical engineering and I always looked forward to going to your class every day. Thank you for being a bright spot in a particularly rough year!!!

I really enjoyed this class and appreciate Dr. Burns and the teaching staff. The past couple of weeks have been incredibly stressful though with all of the quizzes and other exams. I have had to spend the majority of my time trying to complete the quizzes for this class, which has caused me to become very stressed when studying for my other classes. I really liked doing the quizzes for this class and found it to be a very helpful way to learn, but there should be another way to test all of the material at the end of the semester. If more quizzes can be given during the semester so there are less at the end of the semester, I think it would be a great way for students to learn while not being as stressed.

I loved this course! Thank you Professor Burns for being so amazing and understanding! I have never had a professor who truly seemed to care about our learning and well being as professor Burns. I will really miss this class!

Thanks for a great semester!

Professor Burns was really understanding and genuinely wanted us to succeed in this course and learn fluids this semester. I appreciated that he really cared about our concerns and how we wanted to learn the material and did his best to help us and accommodate us and our needs. He was an amazing professor this semester!

The format of this class was really great! One thing that would reduce some stress that we as students have felt from the class is to release the quizzes more consistently/when the content is covered in class. It can be a little overwhelming to open Canvas and see that there are 5 new quizzes that need to be completed while there are other days when we are left with no new quizzes.

Fantastic class, sincerely appreciate your method of teaching.

I really loved this course and learned a lot so thank you very much for all of the time you put in and for being a great teacher!

Congrats on making it through the semester! I hope that this format will spread within the ChE dept. and the rest of the CoE. If any help is needed to automate the quizzes, many students are willing to help! This format is that good that students are willing to work to make it spread! I hope for the best, Jesus loves you and God bless!!

Thank you for all the work you have put into this course. We all really appreciate your genuine concerns about our mental health and how you take our concerns and suggestions into consideration.

Thank you to Prof. Burns and the whole ChE 341 team for all the time and dedication they put into this course, I think the course was really successful!

I really enjoyed the format of this course. I feel as though I've learned fluid mechanics and my stress level was so much lower compared to my other classes. I did not waste so much time wondering if my solution was correct or not on examinations. I could try it, see if it worked, and if not, revisit my work and determine what the problem was. Contrastingly, for my other classes, my answers are mere guesses – I submit, pray for the best, and rarely look back at an answer key. This class/format incentivizes me to learn what my mistake is and why, which is arguably the most important part of learning. Also, as a woman in stem, one of my biggest weaknesses is lacking a voice. I've been talked over many times, and rarely have confidence in my answers/solutions. However, with this format, since I know I'm doing a problem right (or wrong), I have so much more confidence to help others/give advice. I commend Professor Burns for his execution with this course, and I wish more of my courses were like this.

Excellent class, brilliant format that lowers the stress of students and cheating as well as helps students learn better the material This format should be implemented to as many classes as possible. The class does not "punish" students for making a calculation error in the quizzes or for not understanding a specific part of the material since you have for all quizzes minimum three attempts.

I enjoyed your class a lot. It was one of my favorites this semester.

Thank you so much Prof. Burns for accommodating to this remote semester and trying to do something different. If classes are being taught differently, students should also be tested differently, and you've done just that. This class felt fair, although sometimes I felt like I was really pushing the deadlines on some quizzes because of the amount of work in other classes. The format got better with the introduction of the ability to push back the due date on some quizzes. With all my other classes having strict deadlines, it took some stress off of me knowing that I had at least one class that would be a bit more forgiving and understanding, that I'm only human. Some of these classes, like Calc 4 and Organic Chemistry 2, expect me to be some kind of superhuman or something, and I really dislike those classes for that reason. So I thank you for being reasonable and understanding during these hard times, and for being a bright spot in an otherwise bleak and boring semester. Your classes always went by the fastest, and you know what they say: time flies when you're having fun. Well, I guess time flies when you're being taught fluid mechanics by Mark Burns. Once again, Thank You so much for everything!

I appreciate that you've been so considerate during unique circumstances. You've acted in the interest of the students and I respect that.

Thanks for caring about us. Even though you tried to do so through the class structure, you also did so possibly without knowing, like by making the class environment light, funny, enjoyable, and different from other classes.
I do have one comment about the quiz system. Having about half of the class work/points at the end of the semester makes it difficult and stressful to balance studying for finals and getting all the quizzes done on time. I actually have not (and may not) study for the cumulative quizzes because it already takes so long to do the remaining quizzes. I think it may work out better to have a more consistent flow of problems throughout the semester (no pun intended). Other than that, I really did enjoy this class and appreciate how accommodating the entire teaching team was. This has been my favorite class at U of M so far because the class sessions were engaging and fun. Thank you for a good semester!
This was the only Zoom class that I've ever looked forward to. I had no interest in Fluid Mechanics before this class and now I am looking up microfluidic chips and analyzing their diagrams for fun outside of class. This class has saved my mental health this semester. I do have some suggestions if this format is continued in the future (hopefully). I would suggest having a set schedule for the release of these quizzes. I understand that the quizzes were being developed throughout the semester, but in future semesters the quizzes will already be tested so having quizzes released the same time every week would be very helpful for time management. It would also lead to less of a mountain of quizzes near the end of the term. I am currently quite overwhelmed by the amount of quizzes out, but if some of these had been released earlier I would not be as stressed as I currently am. I still prefer this over a single exam, because it means I do not have to cram for 2 hours of straight fluid mechanics. I also believe this format makes this class more accessible for medically challenged students. I have a lot of medical issues and being able to fit the quizzes into my schedule when I feel physically able is very helpful. I have had exams in the past where I feel absolutely awful just by coincidence that day and my exam scores reflect that. Being able to take a day off when I feel sick and do the quizzes at a different time was very helpful for me this semester.
Thank you!!
This class made me confident in my ability to succeed as a chemical engineer and I looked forward to your lectures – they were the high point of my day!
I thoroughly enjoyed this class and hope you continue this format in the future!
This new system is truly revolutionary. This is legitimately one of my favorite courses which I have taken insofar at the university and in my academic career in general. The topics were interesting, format was low stress, and the environment was very chill and positive. Great work!
Professor Burns was one of the two best professors I had at the University of Michigan. Not only he understood what the students were struggling on and answered questions very thoroughly and clearly, but also he treated the students with respect and I could really see him genuinely care about students' mental wellness. He made notorious fluid mechanics doable.
Comment for future classes run under this format is to try and get more of the quizzes out sooner, seeing very little time left and a lot of remaining quizzes is pretty intimidating and the topic focused had been out sooner, the combined could have been done like as soon as the unit was over allowing the quizzes to be spread out throughout the semester a little better, though I realize some build–up is inevitable, it could have been minimized a bit better.