Student Opinion on Teaching Thermodynamics Through Synchronous and Asynchronous Distance Learning

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Abstract

This Evidence-Based Practice paper describes the shift of a third-year biological and agricultural engineering thermodynamics course into 100% distance delivery including both synchronous and asynchronous elements. Public health restrictions on in-person gatherings due to the global COVID-19 pandemic shifted many courses that were previously not considered appropriate candidates for e-Learning to an online platform. This was one of those courses.

Anecdotal evidence from the teaching team suggested that students preferred this online approach to the more traditional class setting. Written reflections and Likert scale survey data were collected from students in the class that transitioned from in-person to online-delivery to determine their course preference, and indicated positive attitudes towards the online-delivery mode. Additionally, test scores from two previous years were compared to current exams to determine if the change in lecture delivery mode had a significant impact on students' performance. It was found that the asynchronous lectures did not harm student learning outcomes.

Introduction

The spread of COVID-19 has dramatically altered higher education in the United States, almost overnight. As of May 12, 2021, there have been over 32 million confirmed cases and 576,814 coronavirus deaths in the U.S. alone [1]. Institutions of higher learning, therefore, have been faced with the challenge of balancing student safety with the quality of their education. In many cases, colleges and universities have transitioned to online learning to "flatten the curve" of coronavirus cases through social distancing [2].

To better understand the impact of the COVID pandemic on higher education it is important to study other major events that have threatened the safety of students. For example, the 1918 Spanish influenza pandemic strongly parallels the current coronavirus outbreak. Although not specifically focused on institutions of higher education, a historical evaluation by Stern et al. [3] evaluated the benefits and tradeoffs that resulted from the closing of U.S. public schools during the pandemic of 1918. Stern noted that for the schools that did remain open, the key to success was clear communication and transparency among health officials, school administrators, and the public.

A more recent event that disrupted education in the United States was Hurricane Katrina, which devastated the Gulf Coast region in 2005. One study found that students who attended New Orleans universities during Katrina experienced more fear, stress, and economic and personal loss, as well as reduced trust in institutions compared to students attending Mississippi State University, located further from the hurricane's impact zone [4]. Students facing the coronavirus pandemic may experience similar emotions, but unlike Hurricane Katrina, COVID-19 is not localized to one area. Therefore, the ubiquity of a global pandemic creates unique challenges for students, faculty, and administrators of higher education institutions.

This case study focuses on the impact of COVID-19 on one junior-level biological and agricultural engineering (BAE) thermodynamics course. Thermodynamics is a required part of the undergraduate curricula for most BAE programs. Kaleita and Raman [5] reported that 94% of BAE undergraduate programs included thermodynamics among their required engineering science courses. In their study of U.S. and European biosystems engineering curricula, Briassoulis et al. [6] listed applied thermodynamics as one of the nine fundamental engineering subjects that were considered mandatory for all specializations of agricultural/biosystems engineering.

An understanding of thermodynamics is also important when working towards licensing as a professional engineer. The process for professional licensing for all disciplines of engineering includes successfully completing two tests managed by the National Council of Examiners for Engineering and Surveying (NCEES): Fundamentals of Engineering (FE) and Principles and Practice of Engineering (PE) exams. The FE exam is usually taken around the time of graduation from an accredited undergraduate engineering program, and the PE exam is usually taken after at least four years of engineering work experience. The FE exam is offered in seven different versions aligning with seven broad categories of engineering: Chemical, Civil, Electrical and Computer, Environmental, Industrial and Systems, Mechanical, and "Other Disciplines" [7]. Most BAE students take the "Other Disciplines" version of the FE. The "Other Disciplines" exam includes nine to fourteen problems in the topic of thermodynamics and heat transfer plus additional questions about thermal properties of materials, turbomachinery, and ideal gas law applications, all of which are common topics in introductory thermodynamics courses [8]. The Principles and Practice of Engineering (PE) exam is offered in sixteen different versions, one of which is the Agricultural and Biological Engineering PE Exam which includes problems on energy balances, energy sources, energy use assessment, thermal properties, psychrometrics, and internal combustion engines, again all of which are thermodynamic topics [9].

The forced transition to distance learning within this thermodynamics course may have resulted in a promising structure that can be built upon after pandemic related social distancing is no longer necessary. Distance learning is an alternative to more traditional, in-classroom settings that lets students take advantage of increased convenience and flexibility. By working asynchronously, students can take classes when and where it is convenient for them, allowing them to study when they are able to concentrate or schedule work hours when they would otherwise be in class. And yet, engineering has significantly fewer online course offerings than other areas of education, even though numerous studies have indicated there is no difference in cognitive outcomes or affective learning [10][11]. Distance learning does limit student's opportunities to interact, collaborate, and receive feedback and social support which can lead to less engagement [12]. Distance learning also requires more discipline and self-motivation from individuals, so it may be particularly beneficial to those with good time management skills and a sense of high self-efficacy. As students and teachers were thrust into the world of distance learning due to the global pandemic, high quality distance education that supports everyone became vital to the success of students.

Course Context

The 4-credit hour course that provides context for this study is a junior-level engineering thermodynamics course based on mechanical engineering thermodynamics (as opposed to a chemical engineering approach to thermodynamics) with some additional biological and biomedical applications. This course itself has been offered annually at the Ohio State University since 2012. A semester-long team design service-learning project was introduced to the course in 2017 and has been incorporated in all subsequent offerings. During the 2018 offering, CATME was added to help structure student team formation [13] and peer evaluation [14] within teams. Papers by Christy et al. and Wilson et al. provide further background information about the course [15], [16].

To adapt to online learning, in-person lectures were replaced with weekly asynchronous lecture slides, some of which were accompanied by a video or voiceover explanation. Laboratory / recitation time and office hours were held through synchronous video sessions via the Zoom software application. Additionally, all midterm and final exams became take-home, with students receiving approximately 36 hours to complete these assignments and submit them to the Canvas-based Learning Management System (LMS). The instructional team held office hours via Zoom as a resource for students to ask clarifying questions before and during the exam. Another change to the course was in the form of in-class worksheets, a feature that had been present since 2015; under COVID conditions the lectures were asynchronous, so worksheets became an additional homework assignment for students. However, worksheets were graded only for completion; students were given access to worksheet answer keys shortly after each deadline. submission deadline.

There were 103 students enrolled in the course during this study. Seventy were BAE students, 32 were biomedical engineering students, and one was a materials engineering student. The instructional team included a faculty member and graduate teaching associate, both of whom are women. The course demographics are summarized in Table 1 below.

Table 1: Course demographics for this Thermodynamics course during Autumn of 2020

Gender	**Students**	**Instructional team**
Female	50 (48.5%)	2
Male	53 (51.5%)	0
Non-binary	0	0
Total	103	2

Experimental Methodology

To better understand the opinions of students regarding the transition of a thermodynamics course to an online platform, the SATS-36 survey [17] was adapted from a statistics course to thermodynamics. This survey was given to all 103 students, but participation was voluntary. It was incentivized by offering all students 1 point of extra credit if 60% of the class competed it. The student perception survey developed for this study used Likert-style assessment scales and was based on the reliable and validated Attitudes Towards Statistics (ATS) originally developed by Wise in 1985 [18]. The ATS test has been validated by numerous authors including Elmore et al. [19] and Shultz & Koshino [20] with high internal consistency between pre- and post-test and high retest reliability. It was intended to asses student attitudes towards statistics courses and the field of statistics as a whole [20]. The ATS was modified by Schau, et al. in 1995 to create the Survey of Attitudes Towards Statistics (SATS) which broadened the assessment to cover four or six factors (depending on the version), instead of the original two [21],[17]. Tempelaar et al.

found that the six-factor version was preferable over the four-factor [22]. This questionnaire was preferable over other similar surveys because it assessed only student opinion without asking students to solve course specific problems, which would be a poor indicator of attitude or ability at the beginning of a course. The full Likert survey can be found in the appendix, but it covers six general attitudes regarding the course:

1. Affect – students' feelings concerning thermodynamics
2. Cognitive competence – attitudes about students' intellectual knowledge and skills when applied to thermodynamics
3. Value – attitudes about the usefulness, relevance, and worth of thermodynamics in the students' personal and professional lives
4. Difficulty – students' attitudes about the difficulty of thermodynamics as a subject
5. Interest – the level of students' individual interest in thermodynamics
6. Effort – the amount of work the student expended to learn thermodynamics

Responses were analyzed within each of the six categories. The questions were coded by the three researchers / coauthors as eliciting either a positive or negative opinion. The average response for each category, organized by positive or negative opinion, was then qualitatively observed, and can be found in the results section.

The average exam grades for students in various offerings of the course, both before and after the transition to distance learning, were used as a proxy to determine if e-Learning had a significant impact on student learning outcomes. An ANOVA was used to compare average scores on midterms and final exams across four years, three before and one after the transition to e-Learning.

Results

A total of 87 responses were collected from a class of 103 students. The responses were analyzed based on the 6 general attitudes and summarized in Tables 2 through 7 below. Students had the highest level of agreement with question 3, "I liked thermodynamics", and the least agreement with "I got frustrated going over thermodynamics tests in class". Overall, there was more agreement with positive statements, ranging from 3.12 to 4.16 (out of 5), than the negative ones, 2.45 to 3.15, regarding the students' affect attitude towards thermodynamics. In addition to the average response and standard deviation, researchers chose to examine the distribution of answers to questions 3 and 19, which can be found below in figure 1. Responses to Question 3 had a much tighter distribution than those to question 19, even though the two questions were about very similar topics.

Table 2: Average responses regarding the attitude 'affect'

Wording	Response	Standard deviation	Question #
Positive	4.16	18.87	3
Positive	3.81	13.12	19
Negative	3.15	9.52	4
Negative	2.45	9.85	15
Negative	2.97	5.12	18
Negative	2.60	9.18	28

Focusing on the positive statements, students had the highest level of agreement with question 6: “Thermodynamics formulas are easy to understand”, overall ranging from 2.44 to 3.77. Within the negatively worded questions, students agreed that “thermodynamics is a complicated subject” and disagreed with “Most people have to learn a new way of thinking to do thermodynamics” with the average responses ranging from 3.05 to 4.09.

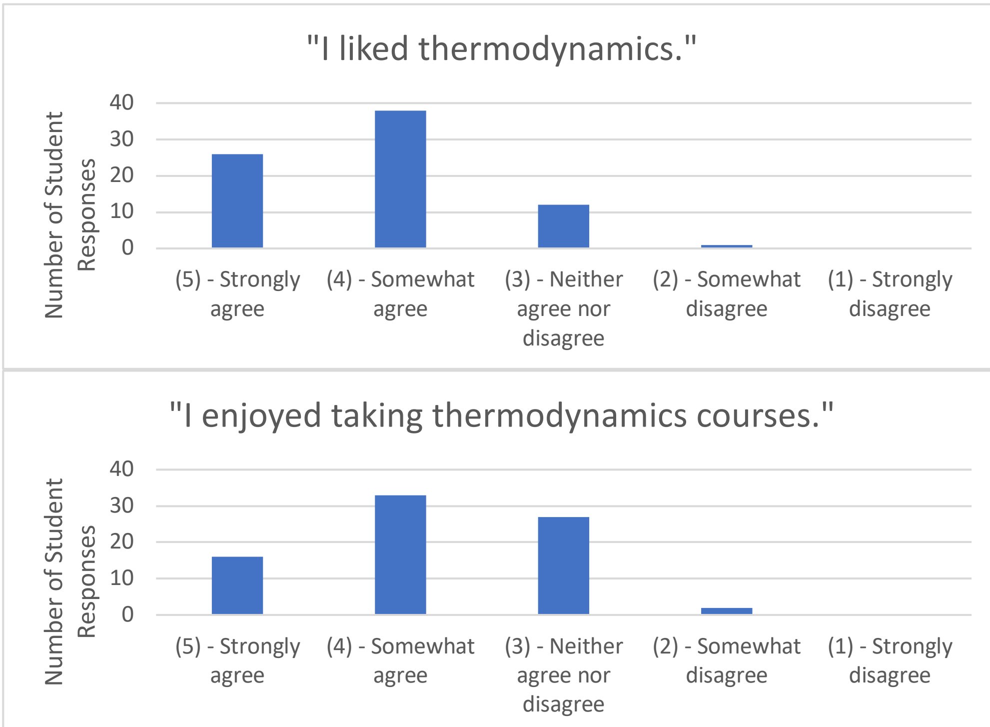

Figure 1: Majority of students viewed learning thermodynamics favorably (positive agreement with survey statements 3 and 19)

Table 3: Average student responses for questions regarding course difficulty

Wording	Response	Standard deviation	Question #
Positive	3.77	14.77	6
Positive	2.44	9.44	22
Negative	4.09	17.23	8
Negative	3.58	12.50	24
Negative	3.28	10.05	30
Negative	3.67	15.04	34
Negative	3.05	11.32	36

Table 4: Average student responses for questions regarding student cognitive competence

Wording	Response	Standard deviation	Question #
Positive	4.47	17.98	31
Positive	4.08	15.68	32
Negative	2.51	7.76	5
Negative	2.23	10.56	11
Negative	2.64	10.65	26
Negative	2.62	11.96	35

Students had the highest level of agreement with question 31, “I can learn thermodynamics”, and the least agreement with “I have no idea of what's going on in this thermodynamics course”. Overall, there was more agreement with positive statements, ranging from 4.08 to 4.47, than negative ones, 2.23 to 2.64, regarding students' attitude about their intellectual knowledge and skills when applied to thermodynamics. The distribution of answers to question 31 can be found in figure 2 where 96% of responders agreed that they can learn thermodynamics.

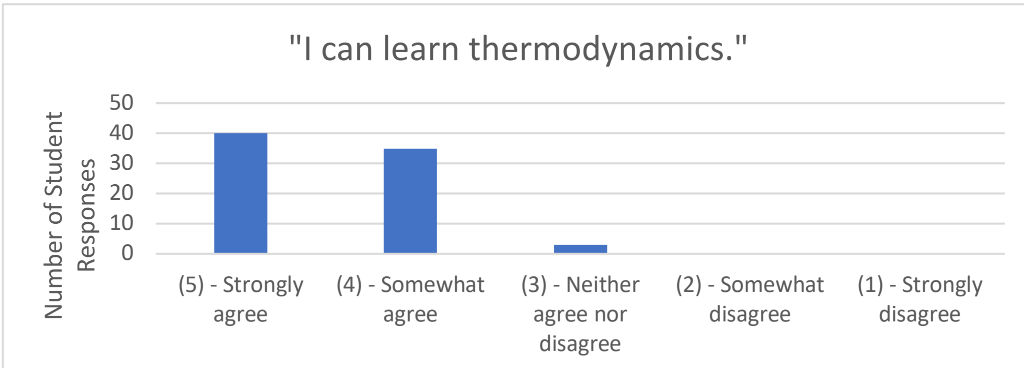

Figure 2: Majority of students were confident about their ability to learn thermodynamics (96% of students agreed with statement 31)

Students agreed most that they "completed all of [their] thermodynamics assignments", question 1, although they disagreed with the statement "I studied hard for every thermodynamics test". Overall, students seemed to agree that they did a lot of work to learn thermodynamics, with all of the average responses at or above a neutral (3) answer.

Students agreed most that they were "interested in understanding thermodynamics information", and while the average response for this was only 3.86 the distribution of answers in figure 3 shows that 76% students agreed with the statement. The most disagreement came from question 12, "I am interested in being able to communicate thermodynamics information to others" with a response of 3.47.

Table 5: Average student responses for questions regarding student effort

Wording	Response	Standard deviation	Question #
Positive	4.51	17.90	1
Positive	4.47	14.69	2
Positive	3.53	8.96	14
Positive	4.08	12.63	27

Table 6: Average student responses for questions regarding student interest

Wording	Response	Standard deviation	Question #
Positive	3.47	11.94	12
Positive	3.68	13.00	20
Positive	3.86	16.06	23
Positive	3.84	13.09	29

Students had the highest level of agreement with question 10, “Thermodynamics skills will make me more employable”, and the least agreement with “Thermodynamics is worthless”. Overall, there was more agreement with positive statements, ranging from 3.33 to 4.12, than the negative ones, 1.65 to 2.55, regarding the usefulness, relevance, and worth of thermodynamics in students’ personal and professional life.

Table 7: Average student responses for questions regarding course value

Wording	Response	Standard deviation	Question #
Positive	3.99	13.31	9
Positive	4.12	14.16	10
Positive	3.33	9.93	17
Negative	1.65	16.09	7
Negative	2.53	10.09	13
Negative	2.55	10.09	16
Negative	2.37	11.00	21
Negative	2.18	9.50	25
Negative	2.14	11.24	33

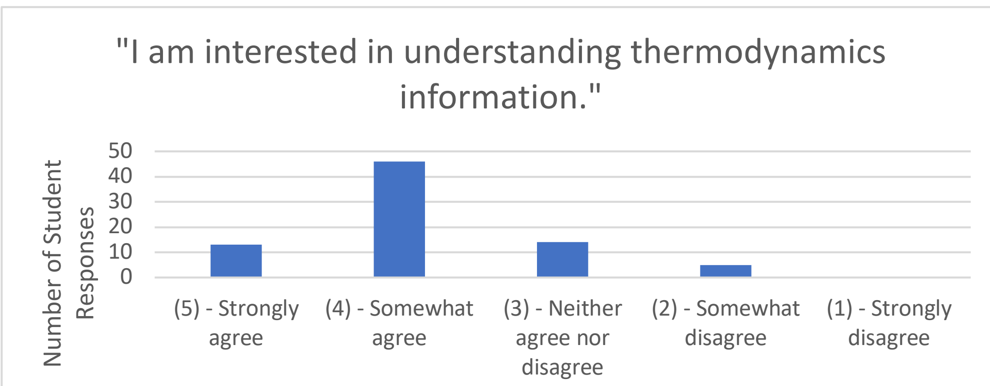

Figure 3: Majority of students valued gaining an understanding thermodynamics (76% of students agreed with statement 23)

Midterm scores from 2020, the class taught through distance education, were compared to 2017, 2018, and 2019 (Table 8) through an analysis of variance using JMP. In 2020, the final exam was made optional to students, so final exam scores were not used in this analysis. At a significance

Table 8: Average midterm exam scores from 2017 through 2020

	Midterm 1	**Midterm 2**	**Midterm 3**
2020	93.72	97.31	90.58
2019	90.05	82.66	83.57
2018	88.82	97.68	85.88
2017	89.99	86.78	84.04

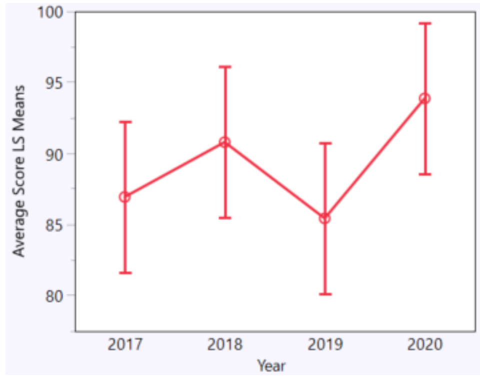

Figure 4: Least Square Means plot comparing year and average exam score

level of α = 0.1, the ANOVA indicated no significant difference between mean exam scores with a p-value of 0.125. The residuals versus normal quantile plot is approximately linear, which indicates that the data are normally distributed. The plotted residuals versus predicted values do not have an obvious pattern, indicating equal variance of the data and satisfying the assumptions for analysis by ANOVA. Finally, the least square means plot shows the effect of year on average scores with 2020 slightly higher than other years, but not significantly above.

Discussion

The high level of student agreement with positive ‘affect’ statements indicates students had generally positive feelings concerning thermodynamics after completing this fully virtual course. Responses regarding ‘cognitive competence’ indicate a positive attitude towards intellectual knowledge and skills when applied to thermodynamics. Students also seem to believe that thermodynamics is a difficult subject that takes time to master. However, they still worked hard in the course, as depicted by their responses to the ‘effort’ questions. Further, they wanted to learn and understand the material, based on their responses in the ‘interest’ portion of the survey. This is likely because they believe that knowledge of thermodynamics will make them more employable and think thermodynamics should be a required part of their training, based on their responses to the ‘value’ questions.

The analysis of exam scores indicated that there was not a statistically significant difference in exam scores between the e-Learning version and in-person versions of the course, but the average scores in 2020 were slightly higher than those of the previous three years. This means that distance learning improved some students understanding of thermodynamics concepts and “did no harm” to the majority of students. Future work in this area will include more years of the online learning format, to have a larger sample size for comparison. Additionally, it could look at the distribution of student grades, to see if this teaching method decreases the difference between the highest and lowest performing groups.

The following sections include anecdotal reflections from the course instructor and graduate teaching assistant. Student reflections are a selection of comments submitted anonymously via the university’s end-of-term Student Evaluation of Instruction surveys.

Instructor reflection:

The transition of this thermodynamics course to online learning went surprisingly well. Course contents (e.g., syllabus, schedule, PowerPoint files, assignments, and other resources) were already well organized within the university’s Canvas-based Learning Management System

(LMS). The course also already used a McGraw Hill eTextbook with adaptive e-Learning reading comprehension questions (LearnSmart) and online AI-graded homework sets (McGraw Hill Connect); these features were particularly helpful for the newly online course delivery system. Students actually read the textbook! Observed improvements during the transition included increased student engagement in the synchronous lab/recitation sessions as well as the highest level of office hours participation I have experienced during my entire faculty career. Instructor preparation was more time-intensive for this distance versus face-to-face versions of the course, involving learning new video capture software, re-imagining how to maintain student engagement in an asynchronous lecture environment, and pre-recording and editing those lectures. In comparison, on-going administrative and grading workloads were fairly similar between the distance learning and traditional in-person versions of this thermodynamics course.

Zoom breakout rooms during synchronous class sessions facilitated student project teams in their work without the distraction of other teams physically nearby. I was especially pleased with how in-class worksheets, which had served as a problem-solving aid and method of recording attendance when used for the in-person offerings of the course, became a central focus for student engagement under online conditions. Students diligently worked in teams and came to office hours to work on their worksheets while I or the course TA was there to guide them and answer questions.

Examination protocols had to be reconsidered in the online environment, and I decided to make them all open book, untimed take-home exams. Previously the exams had been timed, open-book in-class exams; but I was uncomfortable using a tool like Proctorio for on-line test taking. The students reported less stress, and the exam data showed no significant difference in overall exam grades between prior in-person thermodynamics examinations and the on-line version of the course.

During synchronous class time, I found it helpful to be able to seamlessly switch between PowerPoint slides and real-time problem solving on PDF worksheets or past exams using the Notability app via an iPad directly connected to my Zoom computer. I personally found asynchronous lecturing very difficult without student presence and non-verbal feedback, and I do not intend to attempt that in the future. I learned that I much preferred synchronous teaching with the option to post recordings on the LMS for those students who were not able to be present.

Graduate Teaching Associate (GTA) reflection:
Despite the transition to online learning, student participation was high throughout the semester. Almost every office hour had at least one student participate, with many sessions having three or more students. For students who were unable to attend office hours, many chose to send their questions via email.

The number of students who were dedicated to correctly completing the weekly worksheets, which were only graded for completion, was very impressive. Even though answer keys were posted immediately after the assignment deadline, most students took the worksheets seriously and put in the extra effort of asking questions about what they did not understand.

Another way in which students exceeded expectations was through the Mid-Ohio Food Bank project. The final posters and presentations were very cohesive and well organized despite group members only being able to meet through video conferences. In addition, only one project group voiced concern over a conflict among group members. This also supports the idea that the CATME survey successfully grouped together students with complementary leadership skills and work styles.

Undergraduate student reflections:
Student comments were anonymously collected via the university's end-of-term Student Evaluation of Instruction surveys. The following are representative quotes from this cohort of thermodynamics students:

> "COVID made it difficult."
>
> "Even being online this is definitely the class I learned the most and best in!"
>
> "I liked this class and loved the time we actually spent in class."
>
> "…very positive and a fun recitation to attend weekly."
>
> "I greatly appreciated the design component of this class that motivated students to apply concepts from the class into real–world scenarios. The transition to online classes has undoubtedly been challenging for both students and teachers... I was not the biggest fan of the online format for this class."
>
> "I also felt like there were many moving parts to this course: the worksheets, homework assignments, work for homework assignments, textbook readings, team assignments, and exams. Personally it was a lot to keep track of and was sometimes stressful."
>
> "Her procedure for exams was very conducive to the virtual environment. And it felt as if I was actually learning what I needed to for these exams."
>
> "The exams are probably where I learned the most about thermodynamics (where we could bounce ideas off each other and truly solve the problems)."
>
> "I enjoyed the class this semester and enjoyed working on the final project."

Conclusion
In summary, the transition of this thermodynamics course from in-person to on-line went surprisingly well. The elements that helped most included an organized LMS presentation of all course materials, the eTextbook with adaptive learning reading comprehension questions, online self-graded homework sets, virtual office hours, Zoom breakout rooms for student project teams, weekly worksheets, open book take-home exams, and real-time problem solving on PDF worksheets or practice exams using the Notability app. Based on student feedback and instructor reflections, the main four recommendations to improve this course going forward would be to transition to (1) synchronous online large group lectures with video recordings made available for later review, (2) in-person (when safe) small group recitations / labs, (3) a reduced number of different types of assignments, and (4) open-book take-home exams. Based on a recent national survey [23], two other practices that resulted in the most positive impact on student satisfaction nationwide were the inclusion of personal messages to students about how well they were doing in the course and course activities that asked students to reflect on what they had learned and

what they still needed to learn. Although personal messages of encouragement and reflection opportunities were practiced in this thermodynamics course, our plan is to be more intentional about both going forward. In summary, students and instructors in this thermodynamics course demonstrated impressive resiliency during the pandemic-induced shift to 100% online classes, and lessons which were learned in the e-Learning environment can improve post-pandemic engineering instruction.

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Appendix: Survey questions organized by attitude theme addressed

#	Question	Attitude
4	I feel insecure when I have to do thermodynamics problems.	Affect
15	I got frustrated going over thermodynamics tests in class.	Affect
18	I was under stress during thermodynamics class.	Affect
28	I was scared by thermodynamics.	Affect
3	I liked thermodynamics.	Affect
19	I enjoyed taking thermodynamics courses.	Affect
39	In the field in which you hope to be employed when you finish school, how much will you use thermodynamics?	Career Value
5	I have trouble understanding thermodynamics because of how I think.	Cognitive Competence
11	I have no idea of what's going on in this thermodynamics course.	Cognitive Competence
26	I made a lot of math errors in thermodynamics.	Cognitive Competence
35	I find it difficult to understand thermodynamics concepts.	Cognitive Competence
31	I can learn thermodynamics.	Cognitive Competence
32	I understand thermodynamics equations.	Cognitive Competence
40	How confident are you that you mastered introductory thermodynamics material?	Cognitive Competence
8	Thermodynamics is a complicated subject.	Difficulty
24	Learning thermodynamics required a great deal of discipline.	Difficulty
30	Thermodynamics involved massive computations.	Difficulty
34	Thermodynamics is highly technical.	Difficulty
36	Most people have to learn a new way of thinking to do thermodynamics.	Difficulty
6	Thermodynamics formulas are easy to understand.	Difficulty
22	Thermodynamics is a subject quickly learned by most people.	Difficulty
1	I completed all of my thermodynamics assignments.	Effort

2	I worked hard in my thermodynamics course.	Effort
14	I studied hard for every thermodynamics test.	Effort
27	I attended every thermodynamics class session.	Effort
41	In a usual week, how many hours did you spend outside of class studying thermodynamics?	Effort
44	Current grade point average: ___________	Global Post-Secondary Achievement
12	I am interested in being able to communicate thermodynamics information to others.	Interest
20	I am interested in using thermodynamics.	Interest
23	I am interested in understanding thermodynamics information.	Interest
29	I was interested in learning thermodynamics.	Interest
38	How good at mathematics are you?	Math Cognitive Competence
37	How well did you do in your high school mathematics courses?	Prior Math Achievement
45	Number of <u>years</u> of high school mathematics taken: ______________	Prior Math Course Experience
46	Number of college mathematics and/or statistics courses completed (don’t count this semester): _____	Prior Course Experience
43	Number of credit hours earned toward the degree you currently are seeking (don't count this semester); estimate if you don't know: ___________	Progress toward Degree
7	Thermodynamics is worthless.	Value
13	Thermodynamics is not useful to the typical professional.	Value
16	Thermodynamics thinking is not applicable in my life outside my job.	Value
17	I use thermodynamics in my everyday life.	Value
25	I will have no application for thermodynamics in my profession.	Value
33	Thermodynamics is irrelevant in my life.	Value
9	Thermodynamics should be a required part of my professional training.	Value
10	Thermodynamics skills will make me more employable.	Value
21	Thermodynamics conclusions are rarely presented in everyday life.	Value