The Design and Implementation Outcome of an Online Undergraduate Thermodynamics Class

D. Yang and K. Pakala
Boise State University, Boise, Idaho, USA

***Abstract* - Online learning is not common for most undergraduate core engineering courses. However, the growing need for online engineering courses necessitates the design and delivery of online courses that can allow for the flexibility and convenience the distance learning experiences can offer. Thermodynamics is among the most difficult engineering subjects to teach, especially online, where instructors are unable to demonstrate the overwhelming number of equations and applications as they would in face-to-face lectures. This paper describes the design and development of an online, undergraduate thermodynamics class. It reports the implementation outcome of student final course grade and the students' learning experience with thermodynamics in an online environment. The paper also reports students' feedback on the online course and students' responses as to what worked in this particular online course. Implications of the study include a discipline-based design example for engineering educators and a set of practical course design guidelines for online engineering course designers.**

***Index Terms*—Engineering education, online course design, online learning, thermodynamics.**

Introduction

Online learning does not appear to be the common option when approaching undergraduate core engineering courses. However, the growing need for online engineering courses necessitates the development of online courses that can allow for the flexibility and convenience the distance learning experiences can offer. Online learning can also help broaden the participation in engineering education by providing the opportunities to female and adult learners who otherwise will not be able to take the courses due to their family or job responsibilities [1]. Thermodynamics is among the most difficult engineering subjects to teach [2], [3], especially online, where instructors are unable to demonstrate the overwhelming number of equations and applications as they would in face-to-face lectures [4], [5]. This paper describes the design and development of an online, undergraduate thermodynamics class. It also reports the implementation outcome in terms of the students' learning experience with thermodynamics in an online environment, students' feedback on the online course, and students' responses as to what worked in this particular online course.

The online thermodynamics course was hosted in Blackboard, which was the university's online course management system. The content was also made platform-independent such that the students could review the online course materials and complete their homework/quizzes/tests using personal mobile devices/iPads. The following describes the design and overall structure of the online course. Since this was the first online course offered by the mechanical and biomedical engineering department and the first online engineering course for most engineering students, the design of the course emphasized the easy navigation and easy finding of online course materials.

A. *Access Instruction*

Students were provided a general course overview, presented the schedule of activities, instructions guiding the new student to explore the course website, and indicated what to do first, in addition to detailed navigational instructions for the whole course. The headings and titles of various course materials and the setting/organization were designed to provide students easy access to course components without no more than three clicks away. The headings and titles of various course components and the setting/organization of the course materials were made very intuitive so that students knew where to look for specific course materials. Instructions on how to get started and where to find various course components were included in the course materials. In addition, timely Announcements with additional instructions as how to access various homework solutions and online office hours etc. were posted on the course homepage.

B. *Course Introduction*

Students were introduced to the structure of the course. Clear instructions were provided such that the students understood the purpose of the course and how the learning process was structured and carried out, including course schedule, course activities, and assessment.

Etiquette expectations (sometimes called "netiquette expectations") for online discussions, email communications, and other forms of communication were included in the course syllabus. Expectations for email and online forum discussions were clearly communicated to the students. All course and/or institutional policies with which the students were expected to comply were clearly stated, or a link to current policies was provided. All course policies with which students were expected to comply were clearly stated in the syllabus and other forms of communications, such as Announcements and office hours. Minimum technical skills expected of the student were clearly stated. There was a Technical Help section devoted to students who might have problems with Blackboard or other technical difficulties. Additionally, course prerequisites with details of key concepts from those courses were included in the syllabus.

The self-introduction by the instructor was included as part of the course introduction materials. All students were also asked to introduce themselves (post self-introduction) at the beginning of the class. The purpose of the self-introduction was to build a learning community.

C. Significant Learning Goals

The course learning goals focused on several kinds of significant learning, not just "understand-and-remember" the thermodynamics concepts and principles but also applying the learned knowledge and problem-solving. The learning goals/objectives of each chapter were clearly stated at the beginning of each chapter. The course objectives were the same for the traditional face-to-face and the online version of the class. Major learning objectives are listed below:

- Determine properties of real substances, such as steam and refrigerant 134-a, and ideal gases from either tabular data or equations of state.
- Compute heat and work transfer by performing energy balances using the first law of thermodynamics for processes involving ideal gases and real substances as working fluids in both closed systems and open systems or control volumes to determine process diagrams.
- Solve engineering problems using systems and control volumes through the application of the second law of thermodynamics.
- Compute efficiency, work, heat input/rejection, temperatures, pressures, etc., in various cycles via the application of thermodynamics laws and principles applicable to engineering problems.

The online course was delivered in 7 modules addressing the overall course goals listed above. Before students started each module, they were introduced to the learning objectives of that particular module. For example, one of the major course objectives was that students should be able to: compute efficiency, work, heat input/rejection, temperatures, pressures, etc., in various cycles via the application of thermodynamics laws and principles applicable to engineering problems.

D. Course Feedback and Assessment

There were a variety of assessments (quiz and exam as formal assessment; homework and online forum discussion as informal assessment) included in the course. The assignments and the feedback received both from the course instructor and the Learning Assistant (LA) helped the students engage and reflect on their learning. Efforts were especially made to provide timely feedback while things were still fresh in student's minds, such as the instructor returned the graded exams to the shared Google drive immediately after grading. The students would also get quicker feedback on their submitted course work via using the shared Google drive between the individual student and the course instructor.

E. Various Learning Activities

The online thermodynamics course was tough to teach also due to a combination of several different levels of learning objectives (e.g., understanding and applying) and the shorter summer semester term than normal semesters. On one hand, students needed to learn the content in a shorter time period, and on the other hand, they were online and some of them were not able to come to the campus for office hours or LA sessions etc. All these produced a real challenge for the course design. However, the course was designed to mitigate these issues, focusing on offering multiple learning opportunities and encouraging peer learning and tutoring.

The course provided different learning activities, such as students' reviewing recorded videos, recitation videos, online discussions, peer learning and peer tutoring, and LA sessions, which helped student not only learn but also build a great learning community. LA sessions had been proven to support student success. The learning assistants had an important role in the traditional class. The LA session in the online class was to mirror the experiences of the traditional class. "Happy Hour"- a virtual office hour hosted by the instructor was a key element in both versions of the course.

For the recorded videos, the students were able to review the videos as much as they needed. There were also embedded quizzes and questions in the recorded online videos to help students stay on track and to engage students in actively applying their learning. The course connected students to Everyday Examples in Engineering (E^3s)[6], engineering concepts to which students can readily relate. Some E^3s used were: Using a tire gauge to measure the pressure in a bicycle tire, Using mobile devices to find the current outdoor temperature, and then converting that reading to different temperature scales, Discussing open and closed systems and the properties of pure substances while brewing and drinking coffee, Demonstrating a steam engine to explain energy conversion, Illustrating the process of entropy by making a pile of inflated balloons and watching them drift apart. These E^3s were small demonstrations that were done in the traditional class but were made available in the lecture videos for the online class. The course also included active learning activities such as applying the learned principles/knowledge in helping a peer in peer learning groups and peer tutoring sessions. The LA sessions were scheduled time slots when students were encouraged to come to a study area and work in small groups on assignments while an LA or instructor was present to help. All students were not only encouraged to come to the LA sessions but also encouraged to lead the LA session by peer tutoring or explaining a problem to other students. Students who peer tutored or took the lead in explaining a problem to his/her peers would be awarded a peer tutor certificate. A peer tutor certificate was accounted five points (a very small percentage) toward the final grade.

F. Integration/Alignment

Last but not least important, all the major components of the online course were integrated. That is, the learning goals, the materials, the teaching/learning activities, and the feedback and assessment all were closely aligned with and supported each other, which was critical to achieve the learning goals and student's success. The course objectives reflected different levels of learning that necessitated different kinds of assessment. The learning activities provided students the opportunities to engage and reflect (such as the peer tutoring activity). The assessment allowed students to further reflect and self-assess themselves (such as non-graded homework and recitation videos).

Data Collection and Participants

The classes were taught by the same instructor during the data collection period. In summer 2015, the online thermodynamics class was first offered simultaneously with its traditional face-to-face counterpart. In the following two summers of 2016 and 2017, only the online version of the thermodynamics class was offered. An online survey consisting of demographic questions and open-ended questions was administered to all students enrolled in the online thermodynamics classes at the end of the class in summer 2015, 2016, and 2017 respectively. The survey collected both quantitative and qualitative data. Quantitative data include students' survey responses on demographic background, years of experience in online learning, number of online courses taken, etc. Qualitative data include online course design and implementation factors and strategies contributing to student success in the course, as well as student satisfaction, and perspectives on the ease of online courses versus face-to-face courses. Students' feedback and comments on the course design and structure were also solicited in the survey's open-ended questions.

Open-ended survey questions included: 1) What was the most important thing that helped/ensured your success in the ME302 online course? (You can also provide some of the key factors that affected your performance in the online ME302 class.); 2) What were the other important things (except the engineering content) that you gained and learned from the online ME302 class?; 3) What did you enjoy the most in the online ME302 class?; 4) - In your opinion, would some subjects, such as engineering be more difficult to take online than other subjects for example, writing or communication courses? Please briefly explain your opinion.

Twenty-nine (24 male and 5 female) students enrolled in the online thermodynamic from three summer semester, nine from 2015, 15 from 2016, and five from 2017, participated in the online survey. Seventy-six percent of the participants were between 18 to 25 years old. Eighty percent of the participants were juniors, about 13% were seniors, one participant was a sophomore, and one was a second degree seeker. Most of the students were either juniors or seniors. All 29 participants except one were majoring in mechanical engineering.

Implementation Outcomes

Two-thirds of the participants (66%) had taken an online course prior to the online thermodynamics class. One third (34%) of the participants had never taken any online course. However, it was the first online engineering course for almost all the participants (n=28). The researchers first reviewed the students' final course grades for all the students enrolled in both the traditional and online courses in three summer semesters.

A. Student Final Grades

Comparing the online students' final course grades with those of the traditional face-to-face classes offered simultaneously in summer 2015, the online students performed better than the face-to-face students did in terms of course passing grade, the combined percentage from letter grades A+-, B+-, and C+-. (Table 1). A larger percentage of students either failed (21%) or withdrew (4%) from the traditional thermodynamics class than those (0% and 9%) in the online class.

TABLE 1.
STUDENT FINAL GRADES OF ONLINE AND FACE-TO-FACE CLASSES IN SUMMER 2015

Final Grades	Online (N = 11)	Traditional (N = 24)
A+-	18%	37%
B+-	37%	13%
C+-	27%	17%
D+-	9%	8%
F	0%	21%
W/CW	9%	4%

Comparing the final grades of the students of the same course offering in the traditional format and three online course deliveries, it can be concluded that students did not have a disadvantage taking the online version of the class. In fact, three online course offerings of the online version had a larger combined percentage of A+-, B+-, C+- (77%) when compared to that (67%) of the traditional version of the class (Table 2). The DFWs percentage is much lower in the online classes (22%) compared to that (33%) of the traditional class.

TABLE 2.
STUDENT FINAL GRADES OF TRADITIONAL AND ONLINE CLASSES FOR THREE SEMESTERS

Grades	Summer 2015	Summer 2015	Summer 2016	Summer 2017	Online Overall average
	Traditional (N = 24)	Online (N = 11)	Online (N = 16)	Online (N = 8)	
A+-	37%	18%	38%	38%	31%
B+-	13%	37%	38%	0%	25%
C+-	17%	27%	12%	25%	21%
D+-	8%	9%	0%	12%	7%
F	21%	0%	6%	25%	10%
W/CW	4%	9%	6%	0%	5%

B. Important Online Course Design Factors Helped Students Succeed

This section presents the implementation outcomes of the online course from three summers (2015 to 2017) based on the survey responses (N=29) which included both quantitative and qualitative data. All participants (N=29) responded positively about their learning experience in their online thermodynamics class. Most participants would be willing to take another online engineering course.

The most important factor contributing to students' learning was the face-to-face meetings or interactions with the learning assistant (LA), course instructor, and the peers in the LA sessions and instructor's virtual office hours - when the students had the opportunity to ask questions and get clarifications. In the LA sessions, the students also had the opportunity to study and solve problems in the textbooks and previous semester's exam problems together. The LA sessions in this course were intended to provide students an opportunity to ask questions and solve problems in the textbooks or previous semester's exams together not only with the LA but with their peers. As one student wrote, "*The LA sessions were very helpful, my study habits definitely improved in this class. What also helped me was getting a good study group together to work on problems, I would recommend* *that for future students."* Another student explained*, "The LA sessions are a key part of this course. They allow for any questions to be answered on the spot, which further helps with learning the material*."

Another important factor contributed to students' learning and success was the incorporation of multimedia presentations (online videos) of course materials so students could watch and review as much as they could. For example, a student commented, "*Watching the lectures and doing the homework assignments. I enjoyed being able to review the lectures more than once which I couldn't do in a face to face class*." Another student also echoed, "*…the online videos have been the key to learning in this online course*."

The third most prevalent factor identified from the survey responses that contributed to students' learning and success in this online thermodynamics class was time management skills. For example, one student explained, "*The most important thing that help me to be successful in ME302 was being organized, doing the homework and going to the LA sessions.*" Similarly, another student responded, "*Staying on top of the homework and not letting yourself fall behind*." It was also interesting to note that students considered this online course helped them better manage their time because they had to keep up with the intensive summer schedule in order not to fall behind in the course work in the absence of scheduled classroom meetings. Fig. 1 shows the most important factors that helped students succeed in the online class. Some students listed more than one factors although the survey question asked them to list the most important factor.

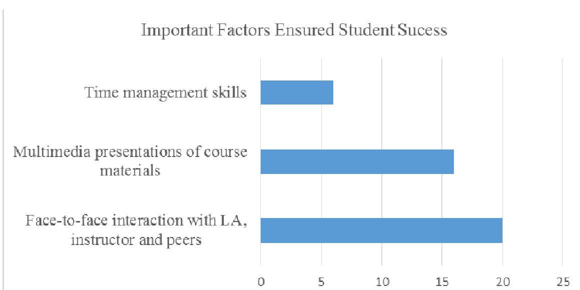

Figure 1. Most important factors contributed to students' success

C. Important Things Rather than Engineering Content Learned

Of the 23 participants who responded to the survey question: What were the other important things (except the engineering content) that you gained and learned from the online ME302 class?, eleven students (48%) stated that they learned to study better and "smart". For example, one student wrote, "*Learning to be able to look at a problem and stop and map out everything one will need to … solve it before actually just diving in and solving the problem has been a big thing I have taken from this course. It has already helped me in other courses I am taking this summer in addition to thermo [this course], and I know it will help me in numerous other classes as well."* Another student also wrote *"[I learner] How to get more value out of the time spent working on classes. … Working with others in an efficient manner*."

Besides gaining a better study habit, ten of the 23 participants (43%) who responded to this open-ended question learned that time management was critical for the success in online courses. A student explained "*I learned how to keep track of my learning and make sure that I was keeping up with the content. This course moved very quickly and keeping up [with the schedule and pace] was key to success."*

D. Most Enjoyed Aspects of the Online Class

Twenty-five participants responded to the survey question asking about the most enjoyed aspect of the online course. The most enjoyable aspects of the online courses for participants were learning the course content (40%), being able to study the course content as much as needed (such as reviewing the online videos anytime and any place) (32%), and flexibility of the course (taking the course while still being able to work) (20%).

E. Is Engineering More Difficult to Learn Online?

Twenty-six participants responded to the survey question asking if they would consider engineering was more difficult to learn online. The majority of the participated engineering students (77%) considered that engineering would be more difficult to take online than other subjects such as English due to the disciplinary difference. They considered engineering was more challenging to take online not because other subjects were simpler in terms of content intensity. As one student provided this thoughtful comment "*I think any online course comes with difficulties and barriers that one must overcome, however I would also have to say that yes, some courses probably come with more of these barriers than others. I don't say that because I think certain courses are simply harder than others, but I do think certain courses where physically solving problems are a big part of the class require more explanation and feedback on errors in a problem solving technique that would be hard to correct online, where as recommendations on say writing technique or editing an essay would be easy to receive and understand through writing or online communication with a professor, as that is how they are given in a normal class setting anyways*."

Conclusion

The study provides a discipline–based example of the design and implementation of an online, undergraduate thermodynamics class [7], which is beneficial for online engineering instructors. It also provides insights regarding effective online pedagogy for teaching tough engineering subjects like thermodynamics. Since most students contributed their learning to face-to-face meetings with learning assistants, course instructor, and their peers, we would recommend that online courses especially for core engineering courses that cover a lot of complex concepts to provide some face-to-face interaction opportunities. During the face-to-face meetings, the instructor can explain some concepts while addressing students' specific confusions more effectively and efficiently. If face-to-face meetings are not possible, a virtual meeting can be scheduled when most students who have questions can tune in could also achieve a similar purpose. Although an online engineering course, such as the online thermodynamics course, takes more effort to design and manage, it certainly offers different advantages for students. These advantages not only include location accommodation and schedule availability but also improved study habits and time management skills.

This study has important implications for engineering education, especially for those instructors who are interested in offering online engineering courses. Based on the results of this study, online engineering courses should include some face-to-face or at least some synchronous meetings via two-way video conferences to provide in-time explanations and clarifications of difficult concepts. Therefore, it is ideal to offer blended engineering courses (the combination of face-to-face with online components) [8], to take advantage of both the online and face-to-face formats, such as online components reduce students' travel and accommodate different schedule and face-to-face meetings allowing solving problem together. It is also recommended that online engineering instructors need to emphasize the peer learning, peer collaboration, and building a good learning community in their online course so that students can learn from and with each other. As instructors, we need to keep in mind that "online learning is as much a social activity as an individual one (p.1)" [9].

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Authors

D. Yang is with the Department of Educational Technology at Boise State University, Boise, ID 83725 USA (email: dazhiyang@boisestate.edu).

K. Pakala, is with the Department of Mechanical & Biomedical Engineering at Boise State University, Boise, ID 83725 USA (email: krishnapakala@boisestat.edu).