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Case Study: A Comparative Analysis of Teaching Modalities in Thermodynamics

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Abstract

In the dynamic landscape of engineering education, instructors face a diverse range of teaching modalities, from traditional face-to-face instruction to hybrid and fully online courses. This case study offers a description of these various teaching modalities when used to teach the same course—Thermodynamics 2. It is shown that irrespective of modality, a well-designed course can foster student success.

Introduction

The purpose of this paper is to describe the details of delivering a specific course, Thermodynamics 2, using three distinct teaching modalities: face-to-face in person, hybrid (with both face-to-face in-person class meetings and an online component), and fully online. The basic assumption guiding this investigation is that the design of a course has a significant impact on its success, putting the chosen modality second to the overarching pedagogical principles.

The traditional dichotomy of face-to-face versus online instruction has given rise to innovative approaches, such as the hybrid model, which combines the benefits of both physical and virtual learning environments. The debate over the value of virtual learning environments continues and this author does not deny the value of in-person learning and value of certain classes, such as lab being taught in-person. This work is based on the belief that student success is dependent on thoughtful course design that transcends the physical or virtual constraints of the learning environment, and that for some courses options to teach online can be beneficial to the students. By dissecting the logistics of each modality, this hopes to identify the similarities and differences that contribute to student success, shedding light on the critical role of course design in engineering education.

While traditional face-to-face instruction has long been the standard method of teaching, the rise of hybrid and fully online courses has introduced new possibilities and challenges. Hybrid courses blend the benefits of face-to-face interaction with the flexibility of online learning, allowing students to engage in discussions, collaborate on projects, and participate in real-time activities. Fully online courses, on the other hand, offer students the convenience of learning from anywhere at any time but require strong self-discipline and time management skills. While each mode has its own advantages and challenges, it is crucial to recognize that the success of students in any format depends on how well the course elements are organized and delivered. Therefore, educators must carefully consider the adaptability and intentional design of their courses to ensure student success in diverse learning environments. This includes incorporating flexible and accessible course materials, providing clear instructions and feedback, and fostering a supportive and inclusive learning environment.

The effectiveness of different teaching modalities in engineering education, such as online versus face-to-face and hybrid models, has been extensively explored in various studies. The following is a summary of some key findings.

An empirical comparison of undergraduate online courses and equivalent face-to-face mechanical engineering courses indicated that the overall learning effectiveness and student satisfaction were equivalent between online and traditional classroom education. The authors conclude “that the overall learning effectiveness of online learning is equivalent to traditional classroom education, and it is not degraded due to the online format of instruction which is the major concern of many educators”. Online students even rated their acquisition of knowledge and the quality of the course marginally better [1]. Furthermore, a study at South Dakota State University based on the development of an Active Learning Cloud Program found that blended/hybrid learning in mechanical engineering courses offered better learning outcomes compared to traditional and online course delivery [2].

A research study by Duan and Bassett shared experiences and lessons learned during the exploration of hybridization between classroom and online teaching in mechanical engineering, suggesting that this blended approach effectively combines the advantages and avoids disadvantages of both modalities. The current assessment indicates it provides a promising alternative for teaching undergraduate courses. [3] Alkhatib explored an interactive learning approach for engineering education, implemented through a flipped classroom model within a blended learning framework. This approach shifts traditional lectures to an online, self-paced format, achieved through the development of interactive modules, concise video lectures, pre-class brainstorming prompts, and theoretical foundations alongside practice exercises. Interactive presentation software is then utilized within the classroom to deliver the modules and engage students in active learning activities. The author demonstrates the effectiveness of this method using a quantitative assessment of program learning outcomes, revealing an average improvement from 3.9 to 4.4 on a 5-point scale. [4]

A study comparing student perceptions of teaching effectiveness and learning achievement in online and hybrid basic communication courses found that overcoming technology constraints and addressing student expectations are crucial for effective learning in these modalities [5] A survey study compared students' perceptions of four class settings: face-to-face, synchronous online, asynchronous online, and hybrid. Results showed traditional face-to-face classes were preferred, while asynchronous online classes were least preferred. Hybrid classes were found to be most flexible, while face-to-face classes had the least flexibility [7]. Research on hybrid teaching during the Covid-19 pandemic highlighted the challenges and considerations for creating effective online and hybrid learning environments, suggesting the need for thoughtful integration of synchronous and asynchronous elements to support learning [6].

These studies demonstrate the importance of integrating various teaching modalities to enhance the learning experience and outcomes in engineering education. The choice between online, face-to-face, and hybrid models should consider factors such as course content, student preferences, and learning outcomes. Overall, the literature suggests that blended/hybrid learning and interactive approaches within a blended framework can enhance learning outcomes in engineering education, while careful consideration of technology and student expectations is crucial for the effectiveness of online and hybrid modalities.

Designing a well-structured course is essential for facilitating student learning and engagement in both synchronous and asynchronous formats. This involves carefully organizing course materials, providing clear instructions and expectations, and incorporating interactive and collaborative activities to promote active learning. Additionally, educators should consider the use of technology tools and platforms that support effective communication and facilitate seamless access to course content. By creating a well-structured course, educators can help students navigate the learning process more effectively and maximize their learning outcomes in both online and in-person settings.

Overview of Teaching Modalities

To investigate the impact of teaching modalities on student success, this paper focuses on the delivery of Thermodynamics 2, a challenging course, at a predominantly undergraduate institution. Three distinct modalities were employed in the study: face-to-face in person, hybrid, and fully online. All courses were taught by the same instructor. The course is required for mechanical engineering students, and all students, typically juniors, taking the course were mechanical engineering majors.

The fully online version of Thermodynamics 2 was offered during a condensed 5-week summer term. Synchronous lectures were held using Zoom twice a week for two hours each, with an additional two hours per week dedicated to class work via synchronous Zoom sessions. The condensed timeframe aimed to allow students to dedicate only part of the summer to taking a summer school course, which allowed many students to still travel. The online format allowed students to take the course from anywhere in the world. Many students had internships in other parts of the country or were living at home to save on rent during the summer term. It is important to note that the condensed format and pace of the fully online course was too fast for some students who decided to withdraw from the course when it became obvious that they could not keep up. The vast majority of students were able to be successful in this fast-paced environment and it did not impact their ability to keep up with the work.

The hybrid and face-to-face classes took place over the following fall quarter, spanning a more traditional 10-week term. The hybrid course met in person on Mondays and Wednesdays, with no class on Fridays, to give students time to complete online quizzes and other assignments. The face-to-face class, on the other hand, met on Mondays, Wednesdays, and Fridays. Each class period was 50 minutes long. This difference in scheduling gave students the opportunity to engage in different degrees of face-to-face learning while also enabling a comparison of the two in-person modalities.

Throughout the study, consistent content delivery was maintained across all modalities to ensure equitable learning experiences. The limitations of the results include student perceptions between the full term, in person and hybrid courses and that the fully online course was during the summer at an accelerated pace.

Course Logistics

The way the three modalities' official class time was structured with the students was the largest distinction between them. During the summer, two sections were taught online. One section met in the morning for two hours each session, three times a week. The second session was held in the evening, twice a week for three hours each day to accommodate students who were interning and were unable to attend classes during the day. The in-person course followed the most conventional schedule, meeting three times a week for fifty minutes each. The hybrid offered one 50-minute online time block per week in addition to two in-person classroom time blocks of 50 minutes each. Table 1 displays the durations of each course class session as well as the typical schedule of assignment work time and in-class lectures.

Table 1 In-class for each modality and schedule of lecture and working time.

Modality	Monday	Wednesday	Friday
Online MWF	2-hour lecture block with time to work on assignments	2-hour lecture block with time to work on assignments	2-hour time block for working on assignments online with instructor
Online MW	3-hour time block 2 hours of lecture time, 1 hour working time	3-hour time block 2 hours of lecture time, 1 hour working time	
Face-to-Face	50-minute time block In-class quiz every other week, lecture	50-minute time block Short lecture with time to work in class on assignments	50-minute time block Short lecture with time to work in class on assignments
Hybrid	50-minute time block Lecture with minimal time to work in class on assignments	50-minute time block Lecture with minimal time to work in class on assignments	50-minute time block Optional online via Zoom working time with instructor

A comparison of the modalities and their organizational structure is provided in Table 2.

Table 2 A comparison of the course aspect for the three modalities.

Modality	Organized Canvas LMS	Use of EES	Formative Quizzes	Recorded and posted Lectures	Assignment Canvas Submission	Office hours
Online	x	x	online	x	x	Zoom only
Face-to-Face	x	x	in-class	x	x	in-person and via Zoom
Hybrid	x	x	online	x	x	in-person and via Zoom

The course design for thermodynamics was based on a modified version of flipped classrooms to allow for more in-depth discussions and problem-solving exercises during class time. Even before teaching online classes hybrid courses, the instructor taught using a flipped classroom. Students received an outline of notes to go along with the assigned textbook reading for each module or topic, as well as pre-recorded mini lectures to watch before class. A quiz on the pre-class material was given to the students. For both online and hybrid courses, the quiz was given online through the course management system. The quiz was given in class for the in-person mode. Online, the students had two chances to complete the quizzes so they could reflect on their errors. The in-class quiz was also administered twice: once to each student individually and again in groups of four to six, where they had to debate the questions and answers before determining the right response. The instructor was able to determine how well the students understood the pre-class material by administering this formative, multiple-choice quiz, which also allowed her to address any misconceptions directly after the quiz, or in the following class session. The quizzes were appreciated by the students to keep them on track, as one student points out in the student course evaluation for the online course: “Formative quizzes and entry tickets were helpful in gaging gaps in understanding.” Having low-stakes quizzes decreases the temptation to cheat and no issues of academic integrity were observed for any class.

Following the quiz, the instructor gave a lecture on more challenging or complex material and provided examples of thermodynamic analyses. Zoom was used to record each lecture. Because everything was on Zoom, the online course was easy to record. A Zoom meeting was opened for the hybrid and in-person classes, and the lecture was delivered using a tablet whose screen could be shared online for recording as well as projected into the classroom. Zoom recordings of the lectures were posted online within 24 hours following each class session. Students were then able to review the material at their own pace, making it an excellent resource for those who might have missed a class. Following the lectures, there was time for questions and to work on assignments for the course. Students were able to apply and put into practice the concepts covered in class as a result.

As a single point of contact for all student resources, the Canvas Learning Management System (LMS) was crucial in setting up the course materials in all three courses. Five modules, spanning one to two weeks of instruction, guided students step-by-step through the course's progression. The early release of Canvas modules allowed students to have a preview of upcoming topics, which promoted proactive engagement and effective time management. The subpages of each module were named consistently and logically arranged, making the learning process easier to navigate. Each assignment was accompanied by an easy-to-read rubric that explained the standards for evaluation to the students. Assignments were submitted through Canvas for all three classes. The course schedule was clearly laid out, and the instructor showed flexibility by allowing extensions when necessary. Weekly email announcements of upcoming assignments and their due dates, along with verbal cues during lectures to emphasize important dates, provided proactive reminders. Regardless of the modality, this coordinated approach sought to establish a sense of structure and organization, creating a setting that was supportive of student achievement.

Figure 1 displays the module organization in practice. There was an overview page for each module with the calendar and all the assignment’s details. Links to pre-recorded mini-lectures, to all the recorded lectures, and to download lecture notes—both as outlines and those posted after lecture—were all included on the resources page. The Entry Ticket Quiz, the pre-class online quiz, and a link to it are included in Figure 1 as an example for the online or hybrid class. The module's applications and assignments are then listed and linked to each assignment. All the assignments are visible in the students' Canvas calendar and to-do list, and the due dates are all prominently displayed in the module overview.

The following details were included in the Module Overview, which was organized using the same format for every module:

A. **Unit overview:** a brief overview of the subject and the skills that the student will learn.
B. **Learning Objectives:** The module's specific learning objectives. These directly relate to the topic and are more detailed than the learning objectives for the course.
C. **Pre-class content**: tasks students must complete prior to class. This section contains information about how long it should take outside of class and what learning objectives are covered in the content. Figure 3 below provides an example from the Canvas page. listed for the class. Note that the due date would usually be listed here as well.

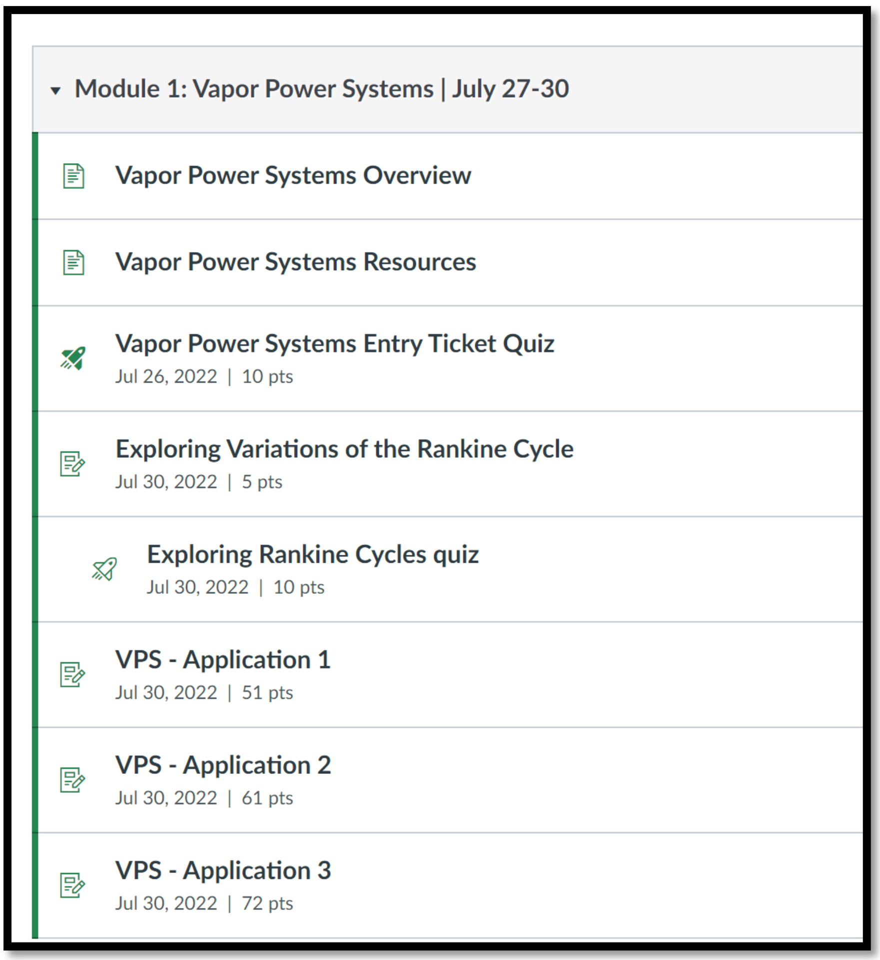

Figure 1 Example from Canvas of a module's organization.
Each module has the same outline.

Pre-class content:

For Wednesday (1-2 hours outside class time): ***All content supports learning objectives 1-3***

1. Review and fill in supplemental notes on Rankine cycles
2. Read textbook: Chapter 8.1 to 8.4, specific sections, and pages denoted in supplementary notes to guide reading
3. Short Recorded Mini-lectures

Figure 2 Example of information given to students for the pre-class work. On the Canvas page the links go to the resources page.

D. **Entry "Ticket":** details about the quiz based on the material covered before class. To help students prepare for the quiz, information is provided such as the date of the quiz (face-to-face only), the link to the online version (for both online and hybrid classes), and a summary of the topics covered (e.g., "a 10-question multiple-choice quiz that covers concepts and vocabulary of the systems, no calculations").

E. **Class Outline:** The class outline includes information on the learning objectives covered, links to assignments, an explanation of what will be done during meetings, and an estimate of the amount of time that will be spent outside of class. Refer to Figure 3 for an example.

Class outline:

In class, we will start the following applications. You will work in groups to support peer learning and the instructor will walk around answering questions. These activities will help you master the learning objectives listed above.

1. Application 1: Simple Rankine Cycle
2. Application 2: Rankine Cycle - Reheat Pressure
3. Application 3: Combined Heat and Power System

After reviewing the quiz, answering questions on the material and/or having mini lectures on material each class period, you will have time to work on the applications in groups and ask questions.

All activities support learning objectives 1, 2, 3, 6 and supports the verbs analyze, calculate, evaluate, compare.

Estimated time to complete applications outside of class: 4-6 hours

Figure 3. Example of in-class outline.

F. **Additional outside of class activities**: a list of all the things that students must accomplish outside of class, along with an estimated time commitment. For example, in the "Exploring Variations of the Rankine Cycle" assignment and quiz, students had to change the pressures and the isentropic efficiency of the turbine to see what happened to the cycle's performance when these parameters were changed. This was done using a provided pre-programmed EES file.

G. **Follow up assessment:** Details about the midterm or final exam are included in the follow-up assessment. All of the tests in these courses were take-home assignments that included design or analysis beyond just computing system parameters or performance.

The learning objectives being evaluated and the anticipated time for completion were specified as well.

The use of EES (Engineering Equation Solver) as a tool to solve thermodynamics problems was a common thread among all modalities. With this integration, the instructor could share screen with students to offer real-time support during both virtual sessions and in-class discussions. Dependence on EES not only improved problem-solving abilities, but also encouraged a uniform method for handling complicated calculations in all modalities.

Using the flipped classroom model, every class period included time for completing the assignments. Students were encouraged to work on the assignments in groups, collaborate with their peers, and ask the instructor questions. This allowed for a more interactive and engaging learning experience. As anticipated, peer collaboration worked best in the in-person course because students had more opportunities to interact with one another during the term, and face-to-face meetings in a physical classroom encouraged more direct communication. All students, however, benefited from the allotted working time during the scheduled class periods since it allowed them to arrive to class with partially finished assignments and the assurance that the teacher would be available to answer any questions. For the online courses, students could choose to collaborate in smaller groups in Zoom breakout rooms or to work in the main Zoom meeting space, only interacting with the instructor when necessary. This arrangement allowed students to work quietly from home while still having the opportunity to listen to others, ask questions, and pick up tips from their peers. This synchronous class period served as a virtual replacement for the traditional in-person classroom, fostering a collaborative learning environment.

How the professor can be reached outside of class is critical for a successful class. Zoom office hours were scheduled using Calendly, an online meeting scheduling tool, for all three modalities. In this manner, the instructor was not left waiting for students to show up on Zoom; instead, students scheduled a meeting with the instructor whenever they needed assistance or had questions. For in-person and hybrid modalities, the instructor offered in-person office hours that worked like traditional office hours with designated drop-in times. Emailed questions were also accepted and encouraged from the instructor. Office hours that were available varied by term. Due to the shorter term for the five-week online courses, there were opportunities to schedule meetings for non-class days and evenings as well as on weekends. For the hybrid and in-person courses, in-person office hours were schedule during the day when both the instructor and students were on campus. Evening hours were available for Zoom office hours.

Student Experience

The final grades and the exam grades (total score) were compared across the three modalities to determine whether the modality affected the students' performance in the class. An overview of the grades—average, median, and standard deviation—is provided in Table 3. The mean is less than the median for all modalities and grade assessments, indicating a bias in the data towards lower grades. This indicates that a few comparatively low scores lowered the average. While the mean of the hybrid group is similarly lower than the median, this difference is not as noticeable as it is for the other groups. Although there might be some skew toward lower grades, the reduced standard deviation suggests that the students' performance is more consistent overall. The mean and median values of the online and traditional groups differ more significantly, indicating a stronger impact of lower scores on the total average. Similar to the final grades, for the exam grades, the median is higher than the mean in all groups, indicating a skew towards lower grades. The hybrid class shows the least variability in grades (lowest standard deviation), suggesting more consistent performance.

Table 3 Comparison of final and exam grades across modalities.

Modality	Number of Students	Final Grades	Exam Grades
Online	2 sections – 57 students total	Average (Mean): 88.96 Median: 93.43 Standard Deviation: 10.51	Average (Mean): 82.48 Median: 88.04 Standard Deviation: 13.81
Face-to-Face	2 sections – 54 students total	Average (Mean): 87.74 Median: 91.28 Standard Deviation: 11.30	Average (Mean): 82.06 Median: 86.74 Standard Deviation: 12.96
Hybrid	1 section – 28 students	Average (Mean): 91.71 Median: 93.66 Standard Deviation: 5.25	Average (Mean): 86.04 Median: 89.26 Standard Deviation: 9.03

The Kruskal-Wallis test for significant variation was performed on the final grades. The resulting p-value was found to be 0.2034, which is greater than the common significance level of 0.05, suggesting that there is not enough evidence to reject the null hypothesis. This indicates that there is no statistically significant difference in the median grades among the three modalities. Similarly, the Kruskal-Wallis test was performed on the exam grades. The resulting p-value of 0.4167 is greater than the significance level of 0.05, indicating that there is not enough statistical evidence to reject the null hypothesis and that there are no statistically significant differences in the median exam grades among the three teaching modalities.

The numerical results for the question "Overall, this course was educationally effective" from the student course evaluations are combined in Table 4, in which student score out 5. The findings show that students are generally satisfied with the course's educational value. The average score for every class is higher than 4.0. It's interesting to note that during COVID, when students had no choice but to take online classes and not all online courses were rated high. However, this particular online course, taught post-COVID, had the highest ratings for educational effectiveness out of the courses surveyed here. These high course scores indicate that when students choose to self-select for an online course, particularly in the summer, they are probably prepared for the virtual environment and aware that success in the course will require some level of self-motivation. There was a lot of incentive to succeed because many of the students who took this course did so to get ahead in their classes for graduation and were required to pay extra for the summer term. Furthermore, a lot of students were also enrolled in internships, which could make it challenging to meet the course's 5-week deadline. However, motivated students can succeed in any situation. When they enroll in an online course, they should also be aware of the course requirements for that term. A small number of students dropped out or withdrew when they realized that the time commitment required to work during the summer was going to be too much for them. Student written comments from the course evaluations confirm the course structure was good for the online course, and mentioned the teaching style, class structure, office hours and zoom breakout sessions were especially helpful Some students took advantage of the working time to stay and work the whole time, while others jumped in and out of the Zoom session as needed for questions. This flexibility for the students was key to ensuring students could be successful based on their time constraints.

Table 4

Modality and Section	Student Count Completed	Course Evaluation for the question: “overall this course was educationally effective” Scored out of 5		
		Average	Median	S. Dev
Online MWF	11	4.78	5	0.33
Online MW	7	4.73	5	0.47
Face-to-Face (1)	17	4.54	5	0.66
Face-to-Face (2)	13	4.18	4	0.95
Hybrid	15	4.07	4	1.1

It's likely that some students' dislike for the flipped classroom method contributed to the lower course evaluation scores for the hybrid and in-person sections. These are typical course evaluation scores for this course taught using a flipped classroom by the instructor. Many of the students may not have known what to anticipate from a hybrid course, and in addition to the flipped classroom, they might not have had the same positive impression of the course as the other sections, because this was their first time taking a hybrid class. Even though they thought the hybrid section was the least "educationally effective," the students still received the highest grades of any section. The disconnect between the perception of something as educationally beneficial and the actual learning that takes place has previously been observed in the author's assessments of her flipped classrooms. The most common complaints in written comments are about how quickly lectures are delivered and how much they dislike the flipped classroom model. The majority of students did appear to be aware of the course's resources and were appreciative of the ease of using the resources on a tablet.

Conclusions

The complexities of teaching thermodynamics in three different ways—in person, hybrid, and entirely online—were examined in this study. This investigation is predicated on the basic idea that a course's effectiveness is largely determined by its careful design, with the modality of choice acting as a supporting element. Innovative models such as the hybrid approach are emerging as the educational environment moves beyond the conventional online versus face-to-face dichotomy to include hybrid models that combine the advantages of both virtual and physical learning environments.

Course logistics across modalities for each format has its own distinct features as well as common principles. Consistency in content delivery was fostered by using an organized Canvas LMS and the integration of EES as a problem-solving tool. But the subtleties of scheduling, teamwork opportunities, and office hours highlighted how flexible one must be to fully take advantage of different learning environments.

Techniques used to maximize the benefits of each modality focused on the significance of intentional design, flexibility, and technology integration. By encouraging in-depth conversations and problem-solving activities, the flipped classroom model produced an engaging educational environment. Seamless integration of Zoom, Calendly, and Canvas improved resource accessibility, teamwork, and communication. Each modality's synchronous and asynchronous components were thoughtfully balanced to meet the needs and preferences of a wide range of learners.

The careful planning of course components made it clear how the design affected student engagement and success. A supportive learning environment was enhanced by proactive communication through multiple channels, early course module release, and clear instructions. The well-organized Canvas pages, Zoom recordings, and utilization of formative assessments facilitated comprehension and engagement, transcending the limitations of both physical and online environments. The hybrid class showed the least variability in addition to having the highest average and median exam and class scores, indicating that its students' performance was more constant. The larger difference between the mean and median values in the face-to-face and online classes indicates that the impact of lower scores was more apparent. Statistically, there's no clear evidence that one mode of instruction leads to significantly better median student performance in terms of grades.

Key logistical elements were identified as fundamental for the success of each modality. These included the implementation of a well-structured Learning Management System (LMS) (Canvas at this institution), and the utilization of clear assignment rubrics. Notably, all modalities provided recorded lectures, early access to course modules, structured due dates, and proactive communication via weekly email announcements and in-class verbal reminders.

This study adds to the ongoing conversation about effective teaching strategies by highlighting the fact that students can succeed when instructors carefully craft classes with respect to each modality's advantages. These insights function as guides for educators toward an inclusive and adaptive approach to teaching and learning as educational institutions adopt a variety of pedagogical paradigms. Positive student evaluations and consistent performance across modalities provide evidence that education can flourish in a variety of learning environments with thoughtful design and a dedication to innovation. This study encourages educators to investigate, modify, and improve their methods on a constant basis, recognizing that student-centered, dynamic strategies are the way of the future in education.

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