Flipping the Heat Transfer Classroom

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Abstract
Research in engineering education strongly supports the use of active learning strategies in the classroom. Among the suggested pedagogical strategies, flipped classrooms have received significant attention for engaging students and incorporating deep learning in the classroom. Introductory heat transfer courses are often taught at the junior or senior level of an undergraduate engineering degree using traditional lecture methodologies. Upper-level courses present unique challenges when introducing new pedagogical strategies, especially when it is the first flipped classroom experience for students, which was the case in the first course offering included in this study. Subsequent course offerings occurred after all students had experienced a switch to online learning due to the pandemic.

In this paper, the author shares their approach, experiences, and recommendations for flipping a heat transfer course for seniors in a mechanical engineering program at the University of Evansville, a regional private university. The initial course offering was the instructor's first experience in designing a flipped classroom. It was also the first flipped classroom experience in an engineering course for the students prior to the pandemic. Results include student feedback from mid-semester and end-of-semester evaluations using Likert scale responses and open-ended questions. This paper augments the limited work that has been published regarding flipped classrooms in heat transfer, addressing challenges faced by both the instructor and the students.

Introduction

Research in engineering education strongly supports the use of active learning strategies in the classroom.[1-5] However, introductory heat transfer courses are often taught using traditional lecture methodologies. Among the suggested pedagogical strategies for incorporating active learning, flipped classrooms have received significant attention for engaging students and incorporating deep learning.[6-9]

Flipped, or inverted, classrooms can be designed following a variety of formats.[10-12] Generally, online material is made available for students to review and study prior to attending class. The majority of class time is occupied by active learning strategies where students are expected to apply knowledge from the pre-class assignments. In-class and out-of-class activities can include a wide variety of formats. The goal of flipped classrooms is to actively engage learners while spending more time in higher levels of Bloom's taxonomy.[13]

Few studies have been reported on flipped classrooms for heat transfer courses. In one study, the instructor flipped a heat transfer course for seniors, requiring students to watch full lecture videos outside of class and cold-calling on students to present solutions in class.[14] Student response to the flipped class was overwhelming negative and included concerns about workload, educational benefits, and lack of traditional interactions with the instructor. The authors provided a list of suggestions based on modifications implemented for the second offering of the course.

Another study reported student gains in a flipped heat transfer course, which increased with the second offering of the flipped course.[15] The flipped classroom format described by the report included similar elements as the current study and included two semesters of results.

Introducing new pedagogical strategies presents unique challenges for upper level courses[16,17] such as heat transfer, which is often taught at the junior or senior level of an undergraduate engineering degree. Additional barriers arise when it is the first flipped classroom experience for students. Student resistance and concerns regarding work load are common challenges that may be magnified for upperclassmen, or students further along in their studies.

The course described in this study was required for seniors in an undergraduate mechanical engineering program and met twice a week for 75-minute periods. The 2019 semester included in the study was the instructor's first experience designing a flipped classroom. It was also the first flipped classroom experience in an engineering course for the students. The 2021 semester included in the study occurred after students had experienced online and hybrid courses due to the pandemic. This paper augments the limited published work regarding flipped classrooms in heat transfer and provides recommendations for instructors interested in flipping engineering courses.

Implementation

On the first day of class, the flipped classroom format was introduced, and the instructor discussed the pedagogical benefits supported by research. Course expectations were shared, as well as detailed in the syllabus, which included online video assignments in the course calendar. Slides from a short introductory video were presented in class to familiarize students with the online lecture format. Students were encouraged to take notes when viewing the videos, just as they would in a traditional lecture. Learning and retention benefits were cited for listening, watching, writing, and practicing course material to encourage practiced study. Students were also strongly encouraged to review the online example problems, which were not required for course credit. The instructor also informed students the new out-of-class work would be balanced with dedicated time in class towards homework.

In 2021, students were given a one-page handout on the first day with information about the pedagogical benefits of a flipped classroom, as well as tips for successfully completing a course in the flipped format. In 2019, the instructor also told students they would have a formal opportunity for feedback after Exam 1, from which the instructor would choose to continue the course as a flipped classroom or revert to traditional lecture. Regular feedback and active participation from students were emphasized as keys to success for the course.

2019 was the instructor’s first experience designed a flipped course; however, the instructor had developed an online offering of the course for the summer session immediately preceding the semester. Having already created many of the media files used as online content eased the transition to a flipped course. All online content was organized and shared via the course Blackboard page. Exams followed the same format as traditional course offerings.

Lecture Videos & PPTs

The instructor chose to develop online content using familiar software to focus on content delivery. The instructor also wanted the ability to make quick modifications to online content from any computer at any time. Adopting familiar software also ensured that students were able to access course content with ease.

Lecture videos were created using the Record Presentation function in Microsoft PowerPoint. Research suggests that online lectures should be limited to 6-15 minutes in length to maintain student attention and support effective learning. 25 lecture videos were developed for the course, with 40% being under 10 minutes. The longest lecture video was 15:37 in length. Creating the lecture videos was the most time-consuming element of the course design. For example, one 8-minute video may take four hours to create – this includes the PowerPoint design and animations, audio recording, outtakes, reviewing, and editing. Since students are reviewing the lectures asynchronously, careful consideration of animations and content delivery can provide additional scaffolding and support, which allows students to focus on the appropriate content at that time and identify connections.

The lecture videos were based on instructor notes from previous lecture-based offerings of the course. Lecture videos only included the conceptual content from the instructor's notes; example problems were included as supplementary online content. Simple animations were heavily used to guide students through the material, highlight specifics, emphasize key points, and illustrate the progression of analysis techniques. Adopting PowerPoint for familiarity and accessibility also allowed the instructor to post the PowerPoint slides for students to use for printing handouts and taking notes. Taking notes while watching the lecture videos was highly encouraged in the syllabus and in class, as supported by research on learning and retention.

To provide the students with more flexibility for viewing course videos, the instructor created an unlisted YouTube channel and shared the link with students. Using YouTube allowed the students to access the videos via the YouTube app on their phones, which provided additional flexibility and ease of use on a platform that students were familiar with. YouTube also allows viewers to increase the playback speed, which multiple students commented on using for quick review during the semester.

Example Videos & PDFs

One of the benefits of asynchronous course content is that students can work at their own pace and convenience. Considering the possible range of student needs, the instructor designed the course materials for example problems to be delivered in multiple formats. Initially, the instructor considered creating typed solutions with animations to show the transformations of equations as the analysis progressed, similar to writing a solution on a whiteboard. This option, however, was too time-consuming to pursue for this course offering. Electronically produced solutions would also fail to provide samples from which students could model their submissions.

Instead, the example problems were worked neatly on engineering paper, modeling the solution format required for assignments. Solution steps were annotated to demonstrate the thought process behind each decision. Key steps and historically challenging concepts were highlighted to draw student attention.

After the written solutions were completed, all examples were scanned in color to create PDFs. The color PDFs were then used to create videos where the instructor described the solution process in detail for each example problem. Several software options were considered for creating the example problem and solution videos. The instructor opted for the Windows 10 Game Bar to create a continuous screen capture video that also captured audio. While using the Game Bar video capture, the PDF solution to the example problem was viewed in full screen mode. The cursor appeared as a laser pointer to draw the student's attention to appropriate locations as the instructor described the solution process step-by-step.

Example problems were posted on the course Blackboard page as PDFs (no audio) and videos (full audio) for students to review. The example videos were shared in a second YouTube playlist, which again provided students easily accessible content with options to modify the playback speed. Handwritten PDFs also demonstrated the desired solution process and format for students to imitate.

The content for one example problem could take 1-2 hours to create depending on the complexity of the solution. 43 example problem videos were created. If the solutions had been created digitally, with animations, the time required could easily have doubled. Example problems were the same as those used in the lecture-based offerings of the course. Students were not required to review the example problems; however, students were strongly encouraged to use the example problems as additional practice and study material.

Online Comprehension Checks

One challenge of a flipped classroom is motivating students to complete the pre-work for class. Low-stakes assignments were implemented to extrinsically motivate students to review the assigned lecture videos before class. Online quizzes, or comprehension checks, were assigned on a weekly basis. Weekly quizzes were adopted, rather than conducting a comprehension check before each class, to pre-empt student concerns about workload.

The comprehension checks each consisted of 5 questions that could be quickly answered. The goal of the questions was to highlight key concepts, encourage students to review the videos, and provide students with immediate feedback on conceptual understanding of the assigned material. The quiz assessment function in Blackboard was utilized to create questions, input instructor feedback based on submitted answers, and assign scores. Question formats included: true/false, multiple choice, multiple answer, fill in the blank, numeric answer, and matching After completing an attempt, students could review their answers and automatic feedback from the instructor. Students were allowed two attempts to complete each comprehension check, and the highest grade was recorded.

Comprehension checks typically required less than an hour to create. The most time-consuming element was determining the appropriate questions to demonstrate understanding of key topics, which occasionally included creating schematics or figures.

Classroom Experience

Each class began with some discussion of content from the assigned lecture videos, time for questions from the students, and some questions to gauge limits in student understanding.

Occasionally class began with a brief, single question quiz to check if students had reviewed the assigned video. These quizzes were not announced and were used as an additional low-stakes assignment to motivate students to complete the out-of-class work while also rewarding those students that had. Students began to anticipate these quizzes and were seen reviewing notes and/or videos in the final minutes before class began.

New example problems were developed for the students to practice during class time. Students were encouraged to work in groups before sharing solution techniques with the class. To encourage more discussion and participation, the instructor would occasionally force the students to mix up the groups since students habitually sat in the same location each class meeting. Typically, groups of three to five students worked together in class while the instructor circulated between the groups providing prompts and feedback. After the groups had made significant progress or began reaching roadblocks, the instructor would bring the class together by writing solution steps on the board and describing the concepts or asking students to explain the steps. Often the students could overcome roadblocks by discussing the problem within their group or consulting with a nearby group. Due to the relatively small enrollments in the course, it was difficult for students to avoid participating in class discussions.

In some class meetings, the instructor provided additional resources such as handouts, flow charts, or summarizing materials to help students connect the course topics and identify solution techniques. The vast majority of in-class time was spent working example problems with the students and discussing the material as part of the solution. Usually, one problem was selected from the textbook and the remaining problems were developed or modified by the instructor to include multiple concepts. Students were also asked to identify necessary modifications to the analysis if a physical change was made to the system to demonstrate understanding without re-solving problems.

As an instructor in a flipped classroom, it was necessary to accept uncertainty. Immediate student feedback was used to influence the use of class time rather than a carefully planned lecture. It was helpful to consider common questions or challenges from students from prior semesters, conceptual questions to probe understanding, content summaries to link knowledge, and multiple example problems or variations to problem statements to provide additional guidance and practice where students struggled the most. This meant preparing material that may never be used in class. It also indicated a need for flexibility to meet the students at their level of understanding and adjust prompts or problems to provide appropriate levels of challenge. Class time was not fully scheduled, but multiple options for guiding student learning had been prepared.

To pre-empt expected concerns about additional workload due to online work, the instructor set aside time at the end of each class meeting to begin one of the assigned homework problems. This was advertised to the students as a trade-off for the time required to watch the assigned lecture videos. The length of the video was often not enough time to completely solve a homework problem, but allowed for a symbolic solution to be developed in class. Students also had the opportunity to choose which assigned homework problem would be examined in class.

Results

Results include student feedback from mid-semester and end-of-semester surveys or evaluations using Likert scale responses and open-ended questions. Academic performance is also compared prior lecture-based offerings of the course. Qualitative results are provided from the instructor's evaluation of the course. Results are limited to a small sample size, which represents a single course offering at the instructor's institution.

Mid-Semester Interview on Teaching - 2019

The University offers Mid-Semester Interviews on Teaching (MITs) through the Center for Teaching Excellence. MITs are conducted by a faculty member from a different academic program on campus, and provide the instructor summative feedback in the middle of the semester. Unlike end-of-semester student course evaluations, MITs allow instructors timely feedback to improve the course experience. MITs consist of two questions: "What are the major strengths of this course – what is helping you learn?" and, "What changes would you make in this course to assist you in learning?" Instructors can ask that additional questions be included for a specific course. MITs occur during the final 20-30 minutes of a class meeting and include 5-10 minutes of peer observation from the faculty member. The course instructor is not present during the MIT.

The faculty member administering the MIT instructs the students to answer the questions in groups and share their responses on the board. The faculty member then asks for clarification and student agreement or disagreement with each statement, which also allows for some peer-norming amongst the students. Before the next class meeting, the faculty member meets with the course instructor and reviews the outcome of the MIT. The instructor then addresses the summarized results in the following class, noting which changes and can be made for the remainder of the course and providing pedagogical reasons for changes that won't be adopted.

A MIT was performed on October 15th, 2019 for the course described in the study. The MIT occurred immediately after Fall Break and shortly after the first exam was returned to students. 13 students were present for the MIT, and they discussed the prompts in four groups.

In response to, "What are the major strengths of this course – what is helping you learn?" at least 11 students agreed that working multiple examples in class was beneficial. At least 11 students also agreed that starting the homework in class was helping them. Again, at least 11 students agreed that the flipped classroom was working for the most part and they preferred having active roles in the classroom.

In response to "What changes would you make in this course to assist you in learning?" at least 11 students wanted more reminders for online assignments. The majority of students also thought the homework required too much time to complete and felt like assigning less homework would not hurt their learning since they worked more problems in class. At least 11 students also wanted a brief review of key concepts from the videos at the beginning of class, and a summary of key equations listed either in the videos or uploaded as PDF.

During the MIT, one student voiced complete opposition to a flipped class because, "you can't ask a video questions." The faculty member administering the MIT noted that this student

seemed to be in the minority of opinions throughout the discussion. As the MIT concluded, the faculty member asked, “How many of you, with a few of these minor changes you’ve mentioned, like the flipped classroom for this course?” 11 of the 13 students present responded “yes.”

After receiving feedback from the MIT, the instructor re-organized the course website based on student input, and implemented regular reminders for online assignments. Students expressed satisfaction with the changes. The instructor reminded students that key content was reviewed at the beginning of class meetings and that questions from students could help focus the review to meet their needs. Students were encouraged to generate their own summaries or lists of key equations for the lecture videos based to benefit from the learning that occurs during the process. Some suggestions were also provided for asking questions and seeking help from the instructor when the course felt challenging or confusing. The instructor also took time to thank the students for their role in improving the course and participating in class to make it an effective learning experience. Based on feedback from the MIT, the instructor chose to continue using the flipped classroom approach for the remainder of the semester. A MIT was not performed in 2021.

End-of-Semester Survey & Student Evaluations – 2019, 2021

Students were asked to complete an anonymous end-of-semester survey in addition to the university’s student evaluations in the final two weeks of the semester. The results were self-reported, and the student responses may have been impacted by a number of factors. During the two weeks of collecting responses, the students would also complete Exam 3 (covering radiative heat transfer) and submit a group project requiring 2D, transient analysis using numerical methods. These two assignments are, historically, the most challenging for students and elicit higher levels of frustration.

The survey and evaluations timing also corresponded with a “what if” analysis for student course grades where the instructor provided each student with their overall score and the final exam score required to raise the course grade. The grade analysis was provided to the students because the final exam is optional for this course. Two students in 2019 were aware they were failing the course before the final exam.

The end-of-semester survey consisted of 15 Likert scale and two open response prompts. Of the 15 students enrolled in the course in 2019, 14 students responded. In 2021, 18 of the 20 students enrolled in the course responded to the survey. The first ten prompts were rated on a Likert scale in terms of frequency (always – never). An additional prompt was included on the 2021 survey. Student responses are summarized as percentages in Table 1; the 2021 results are in parentheses.

Approximately 50-60% of students said they *Always* or *Often* watched the assigned lecture videos before class. This aligned with the opinion formed by the instructor based on classroom interactions. This also suggests that more accountability should be built into the course for students to watch the videos as assigned. In 2021, the instructor modified the summary in the first 5-10 minutes of class to mimic a mini-lecture in response to the rate of video viewership.

Although the instructor repeatedly encouraged students to take notes and review the online example problems, only about 30% of students reported doing these *Always* or *Often* in 2019, whereas approximately 55% reported taking notes in 2021. Students were also more likely to

watch videos more than once in 2021. Students have been conditioned to passive learning for the majority of their education, and those habits were still visible. Such long-held habits are difficult for seniors to overcome, adding a layer of resistance to the first flipped classroom experience for upperclassmen. The differences noted in 2021 may have been impacted by new student experiences during the pandemic when classes were moved to online or hybrid formats.

Table 1: Survey Results I for 2019 and (2021) course offerings

	Always	**Often**	**Sometimes**	**Rarely**	**Never**	**N/A**
I watched the assigned lecture videos before class	21.43 *(22.22)*	35.71 *(27.78)*	28.57 *(33.33)*	14.29 *(16.67)*	0.00 *(0.00)*	0.00 *(0.00)*
I watched the lecture videos more than once	14.29 *(5.56)*	21.43 *(5.56)*	42.86 *(38.89)*	0.00 *(27.78)*	21.43 *(22.22)*	0.00 *(0.00)*
I asked questions about the videos in class	0.00 *(0.00)*	0.00 *(11.11)*	21.43 *(27.78)*	41.43 *(27.78)*	7.14 *(33.33)*	0.00 *(0.00)*
I took notes while watching the videos	21.43 *(27.78)*	7.14 *(27.78)*	28.57 *(33.33)*	21.43 *(0.00)*	14.29 *(11.11)*	7.14 *(0.00)*
I watched the corresponding example problem videos	7.14 *(16.67)*	28.57 *(5.56)*	14.29 *(11.11)*	21.43 *(16.67)*	28.57 *(38.89)*	0.00 *(5.56)*
I reviewed the example problem PDF files	21.43 *(11.11)*	7.14 *(16.67)*	42.86 *(11.11)*	14.29 *(33.33)*	14.29 *(27.78)*	0.00 *(5.56)*
I utilized office hours	0.00 *(0.00)*	0.00 *(11.11)*	28.57 *(16.67)*	35.71 *(27.78)*	28.57 *(44.44)*	7.14 *(0.00)*
I attempted the homework problems on my own before seeking help	21.43 *(33.33)*	7.14 *(22.22)*	14.29 *(33.33)*	50.00 *(11.11)*	7.14 *(0.00)*	0.00 *(0.00)*
I reviewed the exam reference tables before the exam	42.86 *(72.22)*	7.14 *(16.67)*	28.57 *(11.11)*	7.14 *(0.00)*	7.14 *(0.00)*	7.14 *(0.00)*
I had difficulty accessing the online course material	7.14 *(0.00)*	7.14 *(0.00)*	7.14 *(0.00)*	21.43 *(16.67)*	50.00 *(83.33)*	7.14 *(0.00)*
I reviewed the lecture PPT files *(prompt added to 2021 survey)*	*(11.11)*	*(5.56)*	*(38.89)*	*(22.22)*	*(22.22)*	*(0.00)*

The remaining prompts were rated on a Likert scale from *Strongly Agree* to *Strongly Disa*gree, with two additional prompts included on the 2021 survey. The student responses are summarized as percentages in Table 2, again with 2021 results shown in parentheses.
More than 55% of the students reported Rarely or Never utilizing office hours or attempting the homework on their own in 2019. These results are particularly troubling, and, according to the instructor, the use of office hours was over-reported in the student responses. Faculty at the

institution have noticed an increasing dependence of students on outside resources for homework, which is further enforced by the results reported here. Again, the student responses indicate behavior that could be described as passive learning. In 2021, there was a marked increase in students attempting the homework on their own before seeking help. In both offerings, the instructor reported more impactful interactions due to the flipped classroom environment, in spite of the low number of students utilizing office hours.

Table 2: Survey Results II for 2019 and (2021) course offerings

	Strongly Agree	**Agree**	**Neither Agree nor Disagree**	**Disagree**	**Strongly Disagree**	**N/A**
I prefer the PDF (no audio) examples to the example videos	7.14 *(0.00)*	7.14 *(0.00)*	21.43 *(11.11)*	21.43 *(55.56)*	35.71 *(16.67)*	7.14 *(16.67)*
I felt challenged in this course	42.86 *(38.89)*	35.71 *(55.56)*	21.43 *(5.56)*	0.00 *(0.00)*	0.00 *(0.00)*	0.00 *(0.00)*
I enjoyed the flip classroom approach in this course	14.29 *(11.11)*	28.57 *(27.78)*	14.29 *(38.89)*	14.29 *(16.67)*	28.57 *(5.56)*	0.00 *(0.00)*
I feel like I have a solid understanding of heat transfer concepts after taking this course	21.43 *(33.33)*	28.57 *(50.00)*	42.86 *(16.67)*	7.14 *(0.00)*	0.00 *(0.00)*	0.00 *(0.00)*
The instructor supported my learning in this course	14.29 *(88.89)*	50.00 *(11.11)*	21.43 *(0.00)*	7.14 *(0.00)*	0.00 *(0.00)*	7.14 *(0.00)*
Discussing problems with my peers during class was beneficial to my learning *(prompt added to 2021 survey)*	*(33.33)*	*(55.56)*	*(5.56)*	*(5.56)*	*(0.00)*	*(0.00)*
I prefer a course that is taught by lecture only *(prompt added to 2021 survey)*	*(11.11)*	*(16.67)*	*(44.44)*	*(27.78)*	*(0.00)*	*(0.00)*

While it is clear from the responses that students felt challenged in the course, there was a nearly even split in terms of student enjoyment of the flipped classroom, with a slightly higher rating in 2021. The 2019 results do not agree very well with the MIT responses, where all but one student expressed positive opinions of the flipped classroom. Some of these deviations may be due to the previously mentioned factors impacting students during the data collection time period. In the added prompt for 2021, most students recognized the benefits of peer learning in the classroom. The students in 2021 reported feeling more instructor support, indicating that small improvements made by the instructor based on experiences in 2019 were effective

Students were also given the opportunity to provide feedback for two open response prompts.

Prompt 1: Please include any additional feedback or suggestions that could improve your learning or your experience in this course

Several students chose not to respond to this prompt. Two students suggested additional scaffolding for the numerical methods and 2D transient analysis, which was required for the project with a deadline near the survey date. Two students commented on exam difficulty, which is typical for the traditional lecture offerings of the course, too.

A 2019 student said, "Spend more time with the fundamentals in class." Other responses included: "In my opinion flipped class increased workload without providing significant benefit."; "I like how after the mid-course evaluation [the instructor] changed a few things. That really helped me I just wish it would've happened sooner."

A 2021 student said, "I would make no changes to this class besides maybe a little less hw. Overall amazing course." Another student said, "I personally did not utilize example videos but they helped other students." More than half of the responses in 2021 suggested making no changes to the course.

Prompt 2: Please include any additional feedback regarding things that helped your learning or improved your experience in this course

In each offering, students responded that the online material (videos and PDFs) and having access to review the materials at any time was helpful.

In 2019, comments included, "Great course and I started enjoying thermal science because of the instructor," and "I didn't think it was bad it just had some hick ups [sic] being the first time it was taught like this." One student used this opportunity to vent frustration with the flipped classroom – specifically that they cannot ask a video questions and the time required to complete homework and watch videos outside of class was too great. In response to the prompt, the student mentioned the 2D analysis project as beneficial, stating, "Also because of my project, I have a more vested interest learning about heat transfer."

In 2021, student responses were overwhelmingly positive. Comments included, "The backward's [sic] class style is the strongest feature of this class. I have learned more about this topic than any other class I am taking right now," and "Although I am typically not a fan of the flipped classroom …, this class benefited greatly from its format and made the material much easier to understand and retain." One student said, "I feel as though this class engaged students in material more than any other class."

Student Evaluations

The University requires student evaluations for courses taught by tenure-track faculty; the evaluations are completed by students online at the end of each semester. Student response rates were 93% in 2019, and 45% in 2021. Based on the wording of the prompts, a higher score corresponds to a better rating for the course or instructor. The 2019 student evaluations for the flipped classroom offering were, on average, half a point lower than the traditional lecture offering by the same instructor in the previous academic year. In the same comparison, the 2021

evaluations were, on average, a half point higher than the traditional offering. These comparisons are based on a 47% response rate from the traditional offering of the course.

Overall the 2019 student evaluations were lower than those historically received by the instructor but fell within one standard deviation from the institutional benchmark average. The greatest discrepancy was for the prompt, "Overall, this was an excellent course," to which the student rating was nearly 1.5 standard deviations lower than the benchmark average for the institution. The student rating was 3.00 with a standard deviation of 1.36, with more students agreeing with the statement than disagreeing. The result corresponded with a lower response to the prompt, "I feel that I have done very well in this course."

This trend was reversed in 2021, where student evaluations were higher than average, including nearly half of ratings being at least one standard deviation higher than the institutional benchmark. One of the largest gains was for the prompt, "Overall, this was an excellent course," which students rated 4.78 with a standard deviation of 0.73. This was 1.20 standard deviations higher than the institutional benchmark.

A large body of literature exists on the reliability of student evaluations and can be considered when interpreting the student responses. Ratings for the first offering a flipped classroom were lower than typical (for this instructor and for this course), but the ratings improved with the second offering, even exceeding the ratings of the traditional lecture-based offering. The magnitude of pandemic-related impacts are unclear, but it is expected that ratings would improve over time as the instructor continues to improve the flipped classroom course design.

Academic Performance

Course grades were compared with the flipped classroom offering and the previous two lecture offerings for the heat transfer course offered by the same instructor. The exam averages were all within one standard deviation between offerings. The average scores were a few points higher for the flipped classroom, with the highest averages occurring in 2021. The exam content and format did not change across the course offerings, but problem statements were varied.

The overall course grade was within 2% between the 2018 traditional offering, and the 2019 flipped offering. The overall course grade in 2021 was approximately 5% higher. The differences suggest a slight improvement in comprehensive knowledge retention for the flipped course. Due to the small sample size, there was not a statistically significant difference in the course grades for any direct comparison of grades.

Instructor Evaluation

From the instructor's point of view, the flipped classroom provided additional opportunities for the heat transfer course that weren't possible following a traditional lecture format. While it did require a significant upfront time investment to prepare the online content and delivery methods, as well as generate new example problems for class, the flipped classroom approach allowed the students and instructor to discuss a wider variety of applications in class. The instructor witnessed more critical thinking as the students discussed solution techniques and appropriate simplifications for changing systems. Peer learning occurred both in intra- and inter-group discussions in class. Students had more opportunities to learn from applying the material and

making mistakes. The instructor found this to be particularly beneficial, especially considering the low frequency for which students reported attempting the homework on their own before seeking outside help, as reported in Table 1.

In 2019, the students became less pro-active at reviewing the online content later in the semester, as evidenced by "ticket-in" prompts, which may partially explain the difference in student responses in the 2019 MIT and end-of-semester survey. The flipped classroom approach requires students to be pro-active in their learning. If students revert to passive-learner habits, their experience in the flipped classroom will suffer. In 2019, the instructor found it challenging to continuously motivate students with the pedagogical benefits without sounding like a broken record or making the students feel rebuked for not completing the assigned out-of-class work. This trend was not noticed in 2021, where students seemed less resistive to pre-work and online content, perhaps as an effect of the pandemic.

In both offerings, the instructor witnessed few students attending office hours or asking homework questions outside of class. The instructor also experienced significantly fewer discussions and student questions regarding the numerical analysis project than in previous course offerings. While the instructor was pleased with the student engagement in class and does not believe that out-of-class interactions would have changed if the course had been offered in traditional lecture format. Therefore, the flipped classroom appears to have prompted more course-related interactions both between students and with the instructor by providing that avenue in class.

The one student that strongly opposed the flipped classroom approach in 2019 discussed his concerns with the instructor approximately nine weeks into the semester. The student's concerns included a statement that, "students are inherently lazy," which makes the flipped classroom an obstacle for their learning. The discussion allowed the student to unpack his frustration and identify concrete steps that could be taken to address his concerns with the course. The instructor offered alternative approaches and discussed options to improve the individual learning experience. Afterwards, the student and instructor agreed to a bi-weekly pre-class meeting to discuss the course content in more detail. The student only attended one meeting. Other than some feedback on re-organizing the course website, no other students discussed concerns related to the course with the instructor, regardless of the high rating in approachability from student evaluations. In 2021, no student voiced concerns about the flipped classroom approach.

Overall the instructor witnessed notable benefits to the flipped classroom approach for heat transfer. The classroom environment elicited regular discussions and participation from all members of the class. Even shy students appeared more engaged in class and occasionally led group discussions. While academic performance is difficult to compare across multiple course offerings due to differences in students, use of office hours, and other factors, the instructor did feel that students were exploring the course material in ways that would not have occurred in a traditional lecture-based offering. Some students appeared to benefit significantly from the availability of the online course content and the additional guided practice in class.

With a few adjustments from the first offering, the instructor believes the flipped classroom approach will produce students with stronger analytical skills in heat transfer applications.

Limitations

This study was limited to two semesters at one institution, the University of Evansville. The University of Evansville is a private, regional university in the Midwest offering an ABET-accredited B.S.M.E. In 2019, 15 students were enrolled in the course, and all students were male; four students were international and two identified as Hispanic. In 2021, 20 students were enrolled in the course, and one student was female; one student was international, and one identified as Hispanic. The small class sizes limit the ability to make statistically significant claims based on the results. The study will be expanded in the future to include additional offerings, which will provide a larger and more representative sample. Current results from the small sample are still useful for evaluating student experiences in the flipped heat transfer course.

Conclusions

First experiences with any new pedagogical method will present challenges and learning opportunities. It is highly unlikely that any instructor will execute a flawless course offering in the first attempt at a complete course overhaul. Experiences have been shared in this paper to assist engineering instructors in flipping upper-level courses, specifically heat transfer. Student opinions varied on the experience, with pre-pandemic feedback being more positive midway through the semester than at the end of the semester. 2021 feedback was noticeably more positive after students came in with more experience with online and hybrid instruction methods due to the pandemic. The instructor saw significant benefit from the in-class interactions with students as students worked through applications of the course material and discussed solution techniques.

Experiences in the heat transfer course described in this study were overall positive and helped identify areas for improvement in future offerings of the course. In an attempt to provide valuable feedback for future first experience, a summary of the top 10 challenges and recommendations to overcome the challenges associated with a flipped classroom for upper classmen is included here.

Top 10 Challenges and Suggested Approaches

1. Designing the Online (out-of-class) Content
    - Start early – creating digital content takes much longer than writing notes on a board. You will need to re-record audio or video files multiple times. Consider transitioning to a flipped classroom over multiple semesters, if desired.
    - Provide additional scaffolding since material will be viewed asynchronously.
    - Design your own content to fit your teaching style and your course objectives.
    - Audio quality is paramount. Find a quiet place to record and invest in a good microphone, if possible. Practice speaking level, distance from device, speed and enunciation.
2. Keeping video length short
    - It takes careful planning to convey the critical information from a 50-minute lecture in short video segments.
    - Focus on key concepts rather than "flashy" videos.
    - Examples of analytical solutions can be removed from the lecture material
3. Overcoming Student Preconceptions
    - Many students will associate flipped classrooms with extra workload. Discuss the benefits of a flipped classroom, citing pedagogical research, and tips for success.
    - Liken the flipped classroom experience to workforce experience (i.e. new engineers will use resources to learn what is needed to complete a project, but they will also have bosses, mentors, and colleagues to discuss project plans with).
    - Remind students that you are there to help them learn and want them to be successful. Some students will perceive the change in pedagogy as an additional obstacle for an already challenging course.
4. Motivating Students
    - Flipped classrooms require more active participation from students to be truly effective. Reward them with positive feedback that supports a growth mindset for all interactions in class. Praise effort. Use techniques like think-pair-share.
    - Continuously encourage use of all provided course materials. Demonstrate your own buy-in and enthusiasm for the flipped classroom experience.
    - Incorporate low-stakes assignments to extrinsically motivate students. For example: requiring a "ticket in" for each class meeting will motivate students to review the pre-class material. Consider options for connecting all modes of participation to course credit.
5. Getting Students to Ask Questions
    - Stop during class and say, "Ask me 2 questions about…" instead of saying, "Are there any questions?"
    - Use student-generated questions to guide the initial in-class discussions. This could include requiring students to participate in an online discussion board or survey tool, or asking students to bring two questions to class.
    - Collect a "ticket out" to obtain questions from experiences in class that day.
6. Accepting Uncertainty
    - Class time is not fully planned for a flipped classroom and should not be strictly scheduled. Prepare probing and guiding questions for students to discuss.
    - Be prepared to incorporate more lecture if students did not complete pre-work. This includes reverting back to a lecture-based offering, if needed.

- Allow students to set the pace and guide class discussion to meet their needs. Use conceptual questions to determine where to focus class time.
- Prepare multiple example problems and variations of problems to challenge students. It is better to have more examples than you need than not enough.

7. Balancing Expectations
    - Include frequent reminders of course expectations and assignments.
    - Avoid doubling the workload. Students are sensitive to increases in workload and instructors should avoid creating barriers for the flipped classroom. Consider reducing homework assignments or incorporating homework assignments with in-class activities if your grading scheme includes graded homework assignments.
    - Ask for student feedback on course organization, specifically online content delivery. Moving the location of a YouTube link or online assignment can have a surprising impact on student experience.
8. Using Homework
    - While not unique to flipped classrooms, a common concern among faculty is the use of online resources by students to find solutions for homework assignments. The results of the 2019 survey in this study highlight the frequency of student dependence on outside help for homework.
    - Online assignments or quizzes can also be used for student practice. Course management software such as Blackboard allows for many question formats, automated feedback from the instructor, automated grading, multiple attempts, enforced deadlines and more. Once created, reusable online assignments can simultaneously reduce grading and provide immediate feedback to students.
    - To maintain the same expectations for time spent outside of class on a course, it may be necessary to reduce the homework load when switching to a flipped classroom. Keep the federal credit hour definitions in mind.
9. Trusting the Students
    - Encourage students to complete the out-of-class work without tracking all online student activity.
    - Request student feedback early and often. Students can identify modifications that will improve their experience in the course without affecting instructor objectives. Upperclassmen have long-enforced habits and many can recognize obstacles to learning that may be less apparent to the instructor.
    - Temper frustration when it is clear students have not completed the assigned pre-work. Encourage accountability using in-class group activities that require student preparation. Have a backup plan.
10. Expecting Criticism
    - Upperclassmen are well acquainted with the expectations of traditional lecture-based courses and frequently resistant to change. Remember to explain the reason for doing things differently so that students understand the motivation and benefit.
    - Motivating students during the second half of the semester seems to be particularly important, based on the results in this study.
    - Some faculty members may view flipped classrooms as an inferior mode of teaching or suggest that it takes less work. Citing the pedagogical research, describing the course design, inviting peer observations, or sharing stories of lively in-class discussions with students can help reduce such criticisms.

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Biography

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