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# Flipping Core Courses in the Undergraduate Mechanical Engineering Curriculum: Heat Transfer

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## ABSTRACT

Flipped classrooms support learner-centered approaches to improve conceptualization, comprehension, and problem solving skills by delivering content outside the classroom and actively engaging students inside the classroom. While literature in engineering and science education supports and encourages the use of inverted instruction, many core engineering courses continue to utilize the traditional lecture-based format. This report describes the design, development, implementation, and assessment of the flipped core course *Heat Transfer* in the undergraduate mechanical engineering curriculum. In this study, the course was restructured for flipped instruction, utilizing custom electronic media for out-of-class learning and student-centered activities for in-class engagement. Open-ended case studies were created to motivate learning and provide opportunities to apply learned knowledge to real world problems. Comparisons of student performance in flipped and traditional classrooms, as well as student observations and perspectives, are presented to demonstrate the effectiveness of flipped instruction. The report outlines an approach for transforming traditional lecture-based core mechanical engineering courses into flipped courses.

**Key words:** flipped classroom, active learning, heat transfer, mechanical engineering

## INTRODUCTION

Inverted (aka flipped) instruction and coursework has gained applied focus in both post-secondary and K-12 classrooms for at least 15 years [1-9]. Baker used the term "classroom flip" to describe his strategy of putting course materials online through a course management system in order to have more time to adopt active learning strategies while in front of students [1]. Lage, Piatt and Treglia [2] used the term "inverted instruction" to do much the same: using computer-based lectures and student-centered class time to differentiate students' individual needs. In general, flipped instruction frees up time in the classroom for more enriching classroom activities, such as peer-assisted, cooperative and/or collaborative learning [9], problem-based learning [10, 11] and case studies [12–16], and places more responsibility on the students for their learning. Studies have shown students in flipped classrooms had higher test scores and assignment scores, better attendance, and in general thought that the flipped classroom had a positive influence on their learning or class performance [5–8, 10, 17, 18]. Overall, flipped instruction capitalizes on online and technology resources, and on using face-to-face time between students and instructors in an active, engaged way. This is the inverse of traditional classrooms, where classroom time primarily involves instructor-lead lectures, and time outside of class is spent on practice exercises and problem solving.

Core courses in the undergraduate mechanical engineering curriculum, such as *Thermodynamics*, *Fluid Mechanics*, and *Heat Transfer*, have traditionally followed the instructor-lead lecture format (traditional classroom). For example, at our institution, mechanical engineering faculty and instructors have taught *Heat Transfer* for decades using the traditional format, where the majority of class time is dedicated to information transfer and a limited amount on team-based, interactive problem solving. *Heat Transfer*, a content-rich course for mid-level undergraduate mechanical engineering students, utilizes fundamental engineering principles to analyze and design complex thermal systems. The course builds upon previous core engineering courses, mainly *Thermodynamics* and *Fluid Mechanics*, to develop and practice the critical thinking skills and foundational understanding needed to analyze, design, and solve real world challenges. From previous course evaluations, students highly valued the interactive problem-solving components of the course, ranking these activities to be among the most important to their learning. When asked how to improve the course, students frequently requested more problem solving to be done in the classroom with the instructor and with their peers. However, the high demand on classroom time to deliver content in the traditional lecture-based course structure limits the amount and degree to which deep and engaging learning activities can be integrated in the classroom.

Inspired by the success of others enhancing student learning with flipped classrooms, we utilized the flipped instruction methodology to restructure the core course *Heat Transfer*. Student-centered approaches were adopted to develop electronic media for out-of-class student learning and interactive learning activities for in-class engagement of content. This report describes the design, development, implementation, and assessment of the flipped course in our undergraduate mechanical engineering curriculum. In this 3-year study, we developed electronic media, compared student performance in flipped and traditional classrooms, and gathered student observations and perspectives of the flipped course structure. Overall, the work was motivated by three questions: (a) Does flipped instruction help students better learn concepts in a core engineering course? (b) Does flipped instruction improve student problem-solving skills? (c) How do students perceive flipped instruction?

## BACKGROUND

### Why Flip?

A number of recent studies have looked at post-secondary flipped teaching and learning. Stone considers three questions about the benefit of flipped learning include considering whether flipping will impact student learning, student attendance, and student attitudes towards this teaching strategy in two undergraduate biology classes (Genetic Diseases, a small upper level course; General Biology, a large lecture/general education course)[5]. Students in the flipped sessions had higher test scores and assignment scores, better attendance, and in general thought that the flipped classroom had a positive influence on their learning or class performance.

There is a distinction between conceptual change/student-centered vs. information transfer/instructor-centered classroom teaching approaches [19-22]. Student engagement and student-centered teaching approaches are integral to student success. Flipping a class arguably leaves the course more student-centered/conceptual-change oriented than instructor-centered/information-transfer approaches. Richardson summarized 25 years of research, and proposed a model of the process from perspectives of both teaching and learning [19]. Student learning improves in STEM fields when instructors use more conceptual, change-oriented, interactive and student-centered teaching approaches in the classroom, as opposed to traditional, transmission-oriented instruction [23–26]. The Approaches to Teaching Inventory (ATI) was designed to look at the student-centered and teacher-centered approaches to teaching in postsecondary physical sciences classrooms [27]. It has been used across a number of STEM disciplines, as well as non-science areas [28].

### Strategies for Flipping Traditional Courses

While there's no single "method" of flipping a classroom, the basic premise involves using instructor-lead "direct instruction" asynchronously via electronic lectures before class, and student-led "active learning" in class. Bishop and Verleger [9] and Mahoney, Zappe, and Velegol [7] provide extensive reviews of the flipped classroom literature, wherein they highlight the benefits and demonstrated successes of inverted instruction as well as make design and implementation

| | | |
|---|---|---|
| Student Centered Learning | **Teaching Presence** | Provide an opportunity for students to gain first exposure prior to class. Online learning materials give students an opportunity to prepare for in-class activities prior to class. |
| | | Provide an incentive for students to prepare for class, for example, by assigning low-stakes assignments due before class and based on the online materials. |
| | | Provide a mechanism to assess student understanding. Low stakes forms of formative assessment seemed to be effective in preparing students for in-class activities as well as in them doing the out-of-class activities. |
| | **Learner Presence** | Provide clear connections between in-class and out-of-class activities. |
| | **Social Presence** | Provide clearly defined and well-structured guidance |
| | | Provide enough time for students to carry out the assignments |
| | **Cognitive Presence** | Provide facilitation for building a learning community |
| | | Provide prompt/adaptive feedback on individual or group works |
| | | Provide technologies familiar and easy to access |

***Table 1. Nine Design Principles of the Flipped Classroom (Kim et al., 2014).***

recommendations [7, 9], many of which have been utilized in our study. Kim and colleagues looked at three college-level flipped classrooms (an engineering course, a sociology course, and a humanities course), and describe the different ways instructors interpret and apply flipping to their classrooms, student perceptions of the value of flipped learning, and design suggestions for flipped classrooms [6]. Each instructor included different pedagogical activities in class, different out-of-class activities, and different technology use in their flipped courses. Overall, as shown in Table 1, nine design principles were discussed, which mapped onto components important to effective student-centered learning.

In addition to refocusing a course into a more student-centered learning experience (rather than a "sage on the stage" faculty-centered course), the flipped approach also hones in on students using higher-order cognitive strategies, and doing so more often and for a higher-proportion of their in-class learning time. Bloom's Taxonomy of cognitive learning was originally proposed as a developmental range of easier to harder skills in the domains of recall, recognition, and the growth of intellectual abilities and skills [29]. In the 1990s, the taxonomy categories were revised to focus on cognition as an action, focusing on four types of knowledge: factual, conceptual, procedural and metacognitive [30, 31]. Evaluation was demoted to one step below the top of the pyramid, and "Creating" was added as the highest form of cognitive growth and understanding. In a traditional teacher-centered course, most class time is spent on lecturing and sharing of information, where students must focus their energies on remembering and understanding. In flipped learning, remembering and understanding are minor classroom areas of focus. Instead, more class time is spent on applying, analyzing, evaluating, and creating.

Herreid makes the point that simply lecturing students about a topic is not very effective in helping them remember anything about it [32]. The medical profession has been aware of this for many years, and has always used "war stories" to instruct their interns and residents. The formal use of stories, called case studies, was introduced into Harvard University's law and business school about 1900, but was not formalized until thirty years ago at McMaster University when they introduced the storytelling method, called Problem Based learning (PBL), into their medical school curriculum. Examples exist in the literature showing case studies engage students' interest and helps them better appreciate the importance of understanding fundamental principles. Case studies make use of real-world scenarios, rather than academic theory as methodology, to help strengthen students' ability to analyze problems, evaluate alternatives, and make action plans [33]. In case studies, the focus is on student centered learning, where teachers serve as guides for learning and students are in control of the learning process.

Although case studies are not as widely used in teaching engineering courses as they are in college medical, business and law programs, there is a need for practical case studies to motivate and engage students in the introductory engineering courses [11]. Case studies have been implemented in a number of engineering courses with success. Anwar and Ford stated: "Like its law and business school counterparts, the engineering case presents a scenario that practicing engineers are likely to encounter in the workplace. Providing students with case experiences can be viewed as equipping future engineers/engineering technologists with the tools they will need to effectively perform in industry" [12]. The authors used the method successfully to teach an engineering technology course in the fundamentals of semiconductors. Likewise, several others have used case studies in their engineering or engineering technology classrooms to improve learning [13–16].

Motivated by student feedback, our own observations, and inspired by the benefits of flipped classrooms and problem-based learning, we utilized flipped instruction methodology to restructure the core course *Heat Transfer*. Strategically, many campuses are including targeted online learning components in supporting their mission and priorities. Increasingly, chief academic officers view online learning as important to their institutional strategic plan [34, 35]. Investing in campus technology online learning efforts by capitalizing on a new generation of integrated, interactive online learning platforms is seen as a potential venue to enrolling more students, and lessoning the cost of education, while improving the experience, engagement and outcomes of students [36]. RIT has targeted online and flipped learning as strategic factors in planning for future enrollment and course offerings [37]. Thus we had a number of motivations in flipping this course, including pedagogical rationale, institutional push, and increasing student engagement and student-centeredness of our course. We used Kim and colleagues' [6] design principles and Bloom's revised taxonomy to guide our decision processes in designing our flipped course.

**The Traditional Heat Transfer Course**

As part of their core competency in mechanical engineering, our undergraduate students, typically in their third or fourth year, are required to take the course, *Heat Transfer*. In the course, students learn how thermal energy moves by conduction, convection, and radiation in real world systems. Our *Heat Transfer* course focuses on six key concepts: Conservation of Energy, Thermal Circuits, Heat Diffusion Equation, Transient Conduction, Convection, and Heat Exchangers. Each key concept consists of several related topics, which were presented via lectures in class. The lecture-based *Heat Transfer* course, herein referred to as traditional *Heat Transfer*, was taught in a traditional classroom setting (i.e., desks aligned in rows facing a whiteboard/projector screen; 55 student capacity) over a 10-week quarter-based system with four, 50-minute classroom lectures per week and two, 75-minute midterm exam periods per quarter (43 contact hours per course). It should be noted that, in the 2013–2014 academic year, our institution transitioned from a quarter-based system to a semester-based system, meaning semester-based core courses were taught over a 14½-week period with approximately the same number of contact hours as quarter-based core courses (43.5 contact hours per semester vs. 43 contact hours per quarter).

All readings and homework assignments were posted online and in the course syllabus at the beginning of the quarter. Typically, over the course of four class periods, an individual topic was introduced, theory developed, and one to two example problems worked out. The complexity of the problem was often dependent on the time available after the theory was presented in a 50-minute lecture. For topics that bridged several class periods, more in-depth examples were covered. Most problem solutions were instructor-led, but there were occasional student-team-led problem solving opportunities, which were challenging to complete during the time available. A graduate teaching assistant led an optional weekly recitation, where students worked together on a single problem with coaching from the teaching assistant.

Homework was collected weekly and graded for correctness with limited feedback. The primary means of student assessment was two midterms and a final exam. Each exam consisted of ten, multiple choice conceptual or simple problems and two (midterm exam) or three (final exam), closed-form, long answer problems. About 50% of the final exam questions focused on the last 25% of the course content, while the balance focused on the entire course content. During some quarters, teams of students worked on a self-selected, open-ended design and analysis project.

Previous end-of-the-course student evaluations showed that students highly valued the interactive problem-solving components of the course, ranking these activities among the most important to their learning. When asked how to improve the course, students often requested more problem solving to be done in the classroom with the instructor and with their peers. Although we agreed with the students that more interactive activities in the classroom would be more beneficial to their learning, it was a struggle to do so because of the limited time left in the classroom after instructor-led activities. In addition, we observed a large discrepancy between students' class notes and the notes used to guide lectures, primarily due to the fast paced, content-delivery mode of the lecture-based format. The observation caused us to reflect whether the discrepancy significantly affected student learning and success. This was particularly troubling since a portion of our class consists of deaf and hard of hearing students, and studies have shown these students struggle in the traditional lecture-based classroom [38–42].

## DESIGN OF THE FLIPPED COURSE

### Designing the Flipped Heat Transfer Course

The flipped course was taught over a 14½-week semester with two, 75-minute lectures per week (43.5 contact hours) in the same classroom setting as the traditional course (i.e., desks aligned in rows facing a whiteboard/projector screen; 55 student capacity). The course was broken into three (3) different modules: Module 1 – Heat Transfer Fundamentals; Module 2 – Conduction Heat Transfer; Module 3 – Convection & Heat Exchangers. The modules focused on the six (6) key course concepts in *Heat Transfer*, each organized into weekly lessons consisting of several specific technical topics (Table 2). Each weekly lesson was organized into graded activities to represent stages of student learning, development, and assessment utilizing design principles for flipped classrooms [6] and learning styles [29–31]: *Learning*, *Practice*, *Conceptualization*, *Application*, and *Extension*. *Learning* activities encouraged students to participate in the online content each week. *Practice* activities encouraged students to solve problems using learned concepts. *Conceptualization* activities assessed a students' understanding of concepts. *Application* activities assessed a students' ability to apply concepts to solve problems. *Extension* activities motivated learning and assessed students' ability to extend the concepts to solve real world problems. At the conclusion of the course, weekly

| Module | Key Concepts | Specific Topics Included |
|---|---|---|
| 1 | Conservation of Energy | Modes of Heat Transfer, Energy Conservation Equation |
| | Thermal Circuits | Thermal Resistances, Extended Surfaces, Shape Factors |
| 2 | Heat Diffusion Equation | Heat Diffusion Equation, Heat Generation |
| | Transient Analysis | Lumped Capacitance, First Term Approximation, Semi-Infinite Solid |
| 3 | Convection | External Convection, Internal Convection |
| | Heat Exchangers | Design and Analysis Methods |

***Table 2. Key course concepts and included topics.***

| Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday |
|---|---|---|---|---|---|---|
| Review online content<br>Take online quiz before<br>Tues class | | (In Class)<br>Highlight concepts and do examples | Work on HW Problems | (In Class)<br>Do more examples | Complete HW Problems | |
| Work on Case Study | | | | | | |

***Table 3. Weekly course mechanics.***

topics were combined in a *Comprehension* activity to assess students' understanding of all course concepts and their ability to apply them to solve problems.

The weekly course mechanics are shown in Table 3. For *Learning*, before the first class of the week on Tuesday, students reviewed online content, read the textbook, and completed a brief quiz online through the university course management system. This was followed by *Practice*, where Tuesday's class was dedicated to addressing initial student questions, providing highlights of the week's topic, and engaging the class in interactive discussion and initial problem solving activities. On Thursday, class time was spent solving and discussing more complex problems in teams of 3–4 students. Throughout the week, students solved assigned homework problems related to the weekly topic. At the end of each module, students completed an in-class, 30-minute multiple-choice quiz to assess each student's ability to define terms, identify assumptions, and understand concepts (*Conceptualization*). On a separate day, students applied learned concepts to solve well-defined, long-answer problems related to the topics covered in the module (*Application*). Throughout each module, students work on an open-ended case study in teams of 3–4 students (*Extension*). At the beginning of each course, the student teams were formed to support student collaboration during *Learning*, *Practice*, and *Extension* throughout the course.

In the flipped course, the grouping and wording of graded activities was changed from the traditional course to help students appreciate the purpose of each graded component to their learning. As shown in Table 4, six graded activities, *Learning*, *Practice*, *Conceptualization*, *Application*, *Extension*, and *Comprehension,* contributed to a students' course grade. Students were encouraged to work together during *Learning*, *Practice*, and *Extension*, enabling them to collaborate on pre-class online quizzes, homework, and case studies. These activities accounted for 35% of a students' course grade. *Learning* and *Extension* were new learning activities that were not part of the traditional course. Although *Practice* learning activities were used in the traditional course, in the flipped courses there was a great shift to working on problems in class and in teams. Flipped course grading of individual student performance was similar to traditional course grading. Individual student performance on in-class quizzes (*Conceptualization*), in-class midterm exams (*Application*), and the final exam

| Graded Event | Description | Course Grade | Change from Traditional |
|---|---|---|---|
| *Learning* | 10 weekly online quizzes with 5 multiple choice | 10% | New Activity |
| *Practice* | 10 weekly homework sets and team problems | 15% | Increased In-Class Use |
| *Conceptualization* | 3 module-specific quizzes with 10 multiple choice | 10% | Added 3rd Quiz |
| *Application* | 3 module-specific exams with 2 problems | 25% | Added 3rd Exam |
| *Extension* | 3 module-specific open-ended case studies | 10% | New Activity |
| *Comprehension* | 1 final exam with 10 multiple choice and 3 problems | 30% | New Comprehensive Final |

***Table 4. Graded events representing stages of student learning.***

(*Comprehension*) accounted for 65% of a students' course grade. A third quiz and midterm were added to the flipped course, which allowed for a truly comprehensive final exam.

**Pre-Class Online Content (*Learning*)**

To support the flipped course structure, students were required to review content out of the classroom and complete a short online quiz weekly for each topic before coming to class. In addition to assigned textbook readings, universally designed digital media packets (with one high level video *Slidecast* lecture and one detailed audio-annotated digital *Pencast* lecture) and two to four simple example problems were designed and developed for each topic area. Students were encouraged at the beginning of the course to utilize all provided resources before taking the online quiz and throughout the course. As the students gained an appreciation for these resources and for their learning styles, students selected the resources that were best suited for their individual learning styles.

*Slidecasts*, or brief narrated and animated slides generated with Adobe™ Presenter, highlighted key concepts for each weekly topic. An example of a *Slidecast* is shown in Figure 1. Typically lasting 15 minutes, *Slidecasts* provided students with quick exposure to and summary of weekly content. *Slidecasts* could be printed or saved to personal computers or mobile devices for review at any point during the course. *Pencasts*, narrated written lecture notes generated with Livescribe™ Smartpen technology, provided detailed content for each weekly topic in a downloadable interactive PDF file format. An example of a *Pencast* is shown in Figure 2. Pencasts provided each student with the instructors' detailed lecture notes with comments, yet gave them flexibility in the way in which they engaged with the content. In other words, students could print them out to review, play them and click backwards or forwards in the interactive PDF to review, add their own notes, and/or play and rewrite the notes in their own style, among other variations. Like *Slidecasts*, *Pencasts* were available for the students to review at any point during the course. Both *Pencasts* and *Slidecasts* were

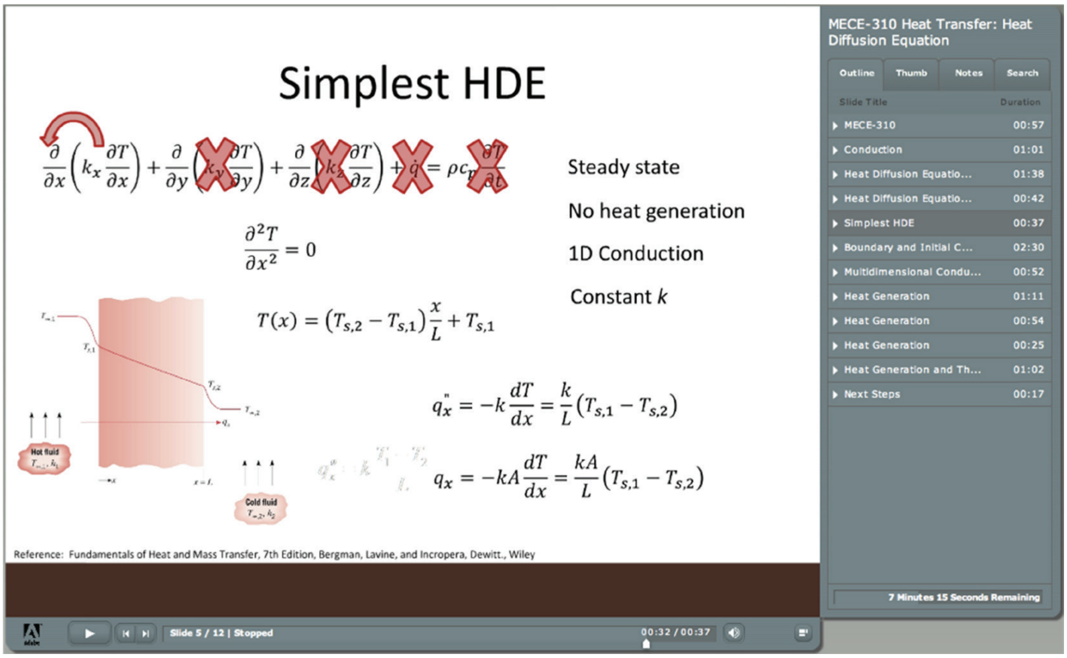


***Figure 1. Screen capture from the Heat Diffusion Equation weekly topic Slidecast.***

developed utilizing universal design approaches [43], offering animation, narration, and dictation to accommodate all students of ability and different learning styles.

Example problems, designed and developed to highlight the key concepts in weekly topics, were solved and posted as a PDF file for students to review before taking the weekly online quiz. The problems typically consisted of simple applications of the topic theory. After utilizing the digital media, reading the textbook, and/or reviewing the example problems for the weekly topic, students completed a short online quiz. These pre-class quizzes consisted of five multiple-choice questions focused on simple definitions, conceptual understanding, and application of basic models.

### Class Activities (*Practice*)

In the first class of each week, the first 20-30 minutes were dedicated to highlighting key concepts of the weekly topic and addressing students' questions regarding the online content or pre-class quiz. The balance of class time for the week was spent solving problems. After the topic highlight, hardcopy packets, containing problem statements for four to five example problems, were distributed. Several student-centered approaches were utilized during in-class problem solving, including instructor-led problem solving with class input and discussion, student team-led problem solving and discussion, and team-to-team collaborative strategic planning and problem solving. By the end

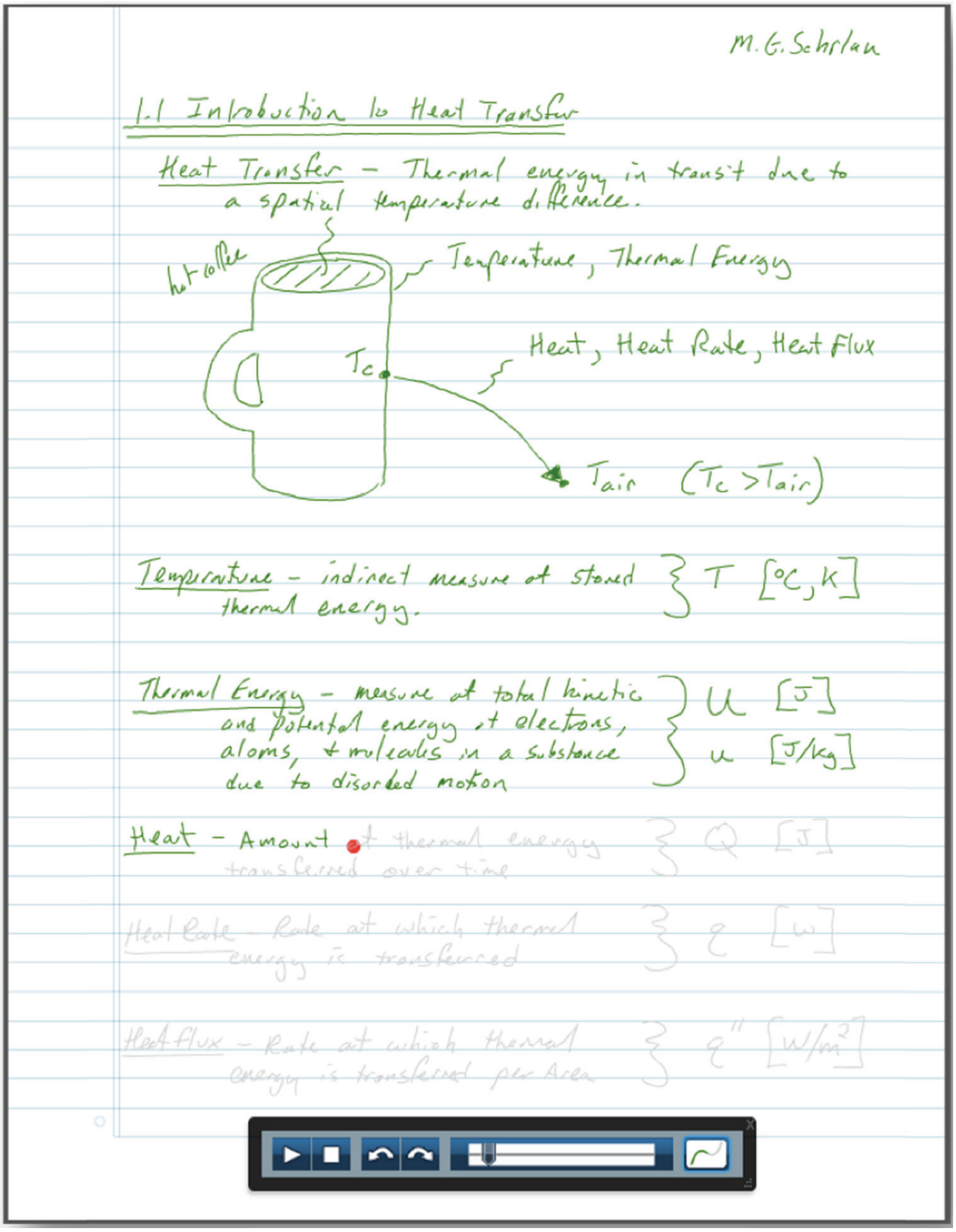


***Figure 2. Screen capture from the Introduction to Heat Transfer weekly topic Pencast.***

of the week, teams were responsible for solving problems completely on their own. To facilitate, we coached teams as needed and encouraged teams to discuss problems amongst themselves. These team problems were collected and graded, which allowed us to immediately understand student misconceptions and provide feedback in a timely fashion. At the end of each week, all solutions to class and team problems were made available through the university's online course management system so students could review while completing assigned homework.

In addition to the in-class problems, students completed assigned homework of four to six textbook problems outside of class. The homework problems assigned in the flipped course were the same as those assigned in the traditional course. The answers and solutions to problems were made available to students at the beginning of the semester through the university's online course management system. Homework assignments were intended as practice to aid in the students learning and were graded on effort rather than correctness. To this end, we stressed that each student needed to take responsibility for how they used the information available to them and encouraged them to struggle with each problem before resorting to viewing the solutions. For each problem, students were required to reflect on how they solved the problem and identify areas of weakness. The intent of this approach was to encourage students to take more responsibility for their learning and recognize areas where they should focus more attention. To receive a homework grade of 100%, a student had to select and complete one or two additional problems, preferably in an area the individual student felt the weakest. After submitting the homework, each student also had to complete a simple online survey rating how confident he or she felt in his or her topical knowledge and solving various types of problems. Each question was mapped to a specific learning objective for the course. The survey questions asked for each topic are available in Appendix A.

**Case studies (*Extension*)**

To encourage development of engineering formulation and deeper problem solving skills, we developed open-ended case studies for each of the three modules and utilized them to motivate student learning and provide opportunities to extend learning concepts to solve real world problems. Case studies were distributed early in the module before covering the content needed to solve the problem. The students worked in teams of 3–4. Each case study required background research to understand a particular technology, development of an engineering problem definition, formulation of a reasonable solution approach, sensitivity analysis, and critique of another teams' solution.

In general, *Extension* required student teams to define the problem, determine and collect the information needed, develop an approach to solve the problem, and propose a final solution in a technical report fully documenting their efforts. In the technical report, student teams were required to examine how their assumptions and uncertainties in input values (e.g. material properties) impacted their final solution. The intent of this critique was to help students develop the skills needed to evaluate the importance of the variables and parameters associated with a problem. Each team also reviewed another team's solution during a 40-minute period in class, where the teams would check for errors and provide feedback on problem documentation. The intent of the peer review process was to help students develop the skills to review the technical work of others and recognizing the importance of fully documenting work. We also provided detailed feedback to the students to promote continual development of the students' problem solving and technical writing skills.

All of the case studies were selected to help students make the connection between course content and real world applications. For example, in the first module, students were tasked to determine whether retrofitting attics with radiant barriers would significantly benefit energy savings in local residential housing. Having little experience with radiant barriers, students were required to research the purpose of radiant barriers, how they are applied and what makes up a roofing system. Unlike a typical well-defined, one-solution homework problem, the radiant barrier problem was loosely defined, requiring students to conduct research in order to make educated assumptions, such as environmental conditions (e.g. ambient temperature and solar fluxes) and materials (e.g., type, quantity, dimensions, and properties), in order to formulate a solvable problem. The same activities appeared in the second and third modules, where student teams were tasked with predicting the performance of an UL-rated fire safe (Module 2) and designing a residential heat recovery ventilator (Module 3). Overall, *Extension* was intended to expose students to real world problems and help them appreciate the societal impact of engineering.

**Assessment (*Conceptualization, Application*, and *Comprehension*)**

Three assessment activities were utilized to assess each student's mastery of course topics at the end of each of the three modules (*Conceptualization* and *Application*) and at the end of the course (*Comprehension*). At the end of each module, students completed a 30-minute quiz and 60-minute exam in class on separate days. The quiz consisted of 10 multiple choice questions to assess each student's ability to define terms, identify assumptions, and understand concepts (*Conceptualization*). In the exam, students applied learned concepts to solve well-defined, long answer problems related to the topics covered in the module (*Application*). Overall, both quiz and exam questions focused on the six key course concepts shown in Table 2. At the end of the course, students completed a comprehensive final exam to assess students' overall understanding of course concepts and their ability to apply these concepts to solve problems (*Comprehension*). The final exam consisted of 10 multiple-choice questions covering all three modules and 3 well-defined long-answer problems, one from each of the three modules.

**Implementing the Flipped Heat Transfer Course**

Two instructors in the fall and spring semesters of the 2013-2014 academic year piloted the flipped *Heat Transfer* course. In each semester, the course was divided into 2 sections of students, each taught by a different instructor. The pilot study consisted of 139 undergraduate mechanical engineering students. Student performance in the pilot was compared to the 6, 10-week quarters, each with 2 sections, of the 2 previous academic years, totaling 269 students. The same two instructors taught all courses to ensure consistency in content coverage and assessment difficulty between traditional and flipped courses. To ensure consistency in the level of difficulty in assessing student performance between flipped and traditional structures, multiple choice questions and long answer problems were recycled, slightly modified, or developed at the same level.

## RESULTS AND DISCUSSION

At the conclusion of the two-semester pilot, the total hours dedicated in class to information delivery, problem solving, and assessment in the flipped and traditional courses were compared. The traditional course spent approximately three times as many total in-class hours on delivering content (six hours for flipped versus eighteen hours for traditional). Here, the information delivery in the flipped course consisted of highlighting the key concepts in weekly topics, versus a comprehensive traditional lecture. In contrast, three times as much time in the flipped class compared to the traditional course was spent on problem solving (thirty hours for flipped versus ten hours for traditional). Both flipped and traditional courses spent the same amount of time on in-class assessment activities.

Student performance in flipped and traditional courses was compared utilizing individual student grades from 408 students taught by the same instructors over a three-year academic period. Student performance in three areas were considered: (i) Course Grade; (ii) *Conceptualization* (10 multiple choice questions per each of the three modules), and (iii) *Application* (2 well-defined long-answer problems per each of the three modules). For each of the three areas, the mean and standard deviation (SD) was calculated. Student T-tests were utilized and P-values calculated to determine statistical significance in student grade means between flipped and traditional structures, where statistical significance occurs when the P-value is less than 0.05. Results of means, SD, T-test P-values, and sample sizes are summarized in Table 5.

### Does flipped instruction help students better learn concepts in a core engineering course?

As indicated by the course grades in Table 5, students in both pilot semesters of the flipped course performed the same overall as their counterparts in the traditional course. Students in the flipped course did achieve slightly higher average course grades than those in the traditional course, although the difference was not statistically significant (flipped vs. traditional course grade mean ± SD; 83.0 ± 9.8 vs 81.5 ± 8.9; P-value = 0.116, as shown in Table 5). However, the results comparing course grades between the traditional course and the pilot in the second semester, where substantive

| | Flipped Course | | Traditional Course | | |
|---|---|---|---|---|---|
| Event | Mean ± SD | n | Mean ± SD | n | P-value |
| *Course Grade* | 83.0 ± 9.8 | 139 | 81.5 ± 8.9 | 269 | 0.116 |
| *Multiple Choice Questions* | 80.0 ± 16.8 | 556 | 72.3 ± 17.0 | 807 | < 0.001* |
| *Closed-Form Problems* | 80.0 ± 21.7 | 1251 | 80.5 ± 19.4 | 1868 | 0.460 |
| Conservation of Energy | 77.0 ± 22.2 | 139 | 59.1 ± 20.4 | 53 | < 0.001* |
| Thermal Circuits | 82.4 ± 16.8 | 278 | 78.3 ± 19.2 | 307 | 0.005* |
| Heat Diffusion Equation | 67.4 ± 27.9 | 278 | 67.9 ± 22.2 | 269 | 0.827 |
| Transient Analysis | 82.6 ± 15.4 | 139 | 86.9 ± 12.8 | 409 | 0.003* |
| Convection | 85.3 ± 15.9 | 278 | 80.1 ± 20.2 | 561 | < 0.001* |
| Heat Exchangers | 89.8 ± 19.8 | 139 | 85.7 ± 18.1 | 269 | 0.046* |

**Statistically significant results, P-value < 0.05*

***Table 5. Summary and comparison of student performance in flipped and traditional Heat Transfer.***

improvements (refining the management and grading of homeworks and classroom activities) were implemented, showed students in the flipped class achieved statistically significant higher average course grades than their counterparts in the traditional course (flipped vs. traditional course grade mean ± SD; 84.7 ± 9.8 vs 81.5 ± 8.9; P-value = 0.013, data not shown in Table 5). However, course grades alone do not provide enough assessment resolution into student performance as it includes scores from all graded activities throughout the entire course. For this reason, further detailed comparison was required.

The mean performance in multiple-choice questions (*Conceptualization*) was compared between students in the flipped and traditional *Heat Transfer* course. As shown in Table 5, overall, students in the flipped course outperformed their traditional class counterparts in multiple-choice questions found in midterm and final exams by almost 8 percentage points (flipped vs. traditional mean score ± SD; 80.0 ± 16.8 vs. 72.3 ± 17.0; P-value < 0.001). Again, multiple-choice questions in the flipped course were recycled, slightly modified, or developed at the same level as those used in the traditional course to ensure comparability. In fact, students in the flipped course consistently outperformed traditional students in multiple-choice questions, even at the module level. These results suggest students in the flipped course have a better understanding of the main concepts in *Heat Transfer* than their counterparts in the traditional course.

**Does flipped instruction improve student problem-solving skills?**

There was no statistically significant difference in overall performance on well defined, closed-form, long answer problems found in midterm and final exams between students in flipped and traditional courses, as determined by mean scores and P-value (flipped vs. traditional mean score ± SD; 80.0 ± 21.7 vs. 80.5 ± 19.4; P-value = 0.460). However, similar to course grade assessment, this comparison did not provide enough resolution into student performance as it combines all key concepts in the comparison. For better resolution of student performance, long answer problems from traditional and flipped courses were categorized into the six key concepts in *Heat Transfer*. Mean scores and standard deviations were calculated from the individual student scores within each of the six key concept areas, as shown in Table 5. The mean scores of the six key concept areas within traditional and flipped courses were then compared using T-tests to determine if any differences were statistically significant. It should be noted that variation in sample size between key concepts and between course structures exists due to the number of times a key concept was assessed in exams throughout the course.

Upon comparing student performance, as tabulated in Table 5 and plotted in Figure 3, we found that students in the flipped course outperformed their counterparts in the traditional course in 4 out of the 6 key concepts (all P-values < 0.05): Conservation of Energy, Thermal Resistances, Convection, and Heat Exchangers. We believe the higher performance of students in the flipped class is due to having significantly more time in class for discussion and problem solving in these areas. This is especially the case with Energy Conservation, a topic that students are typically exposed to a year

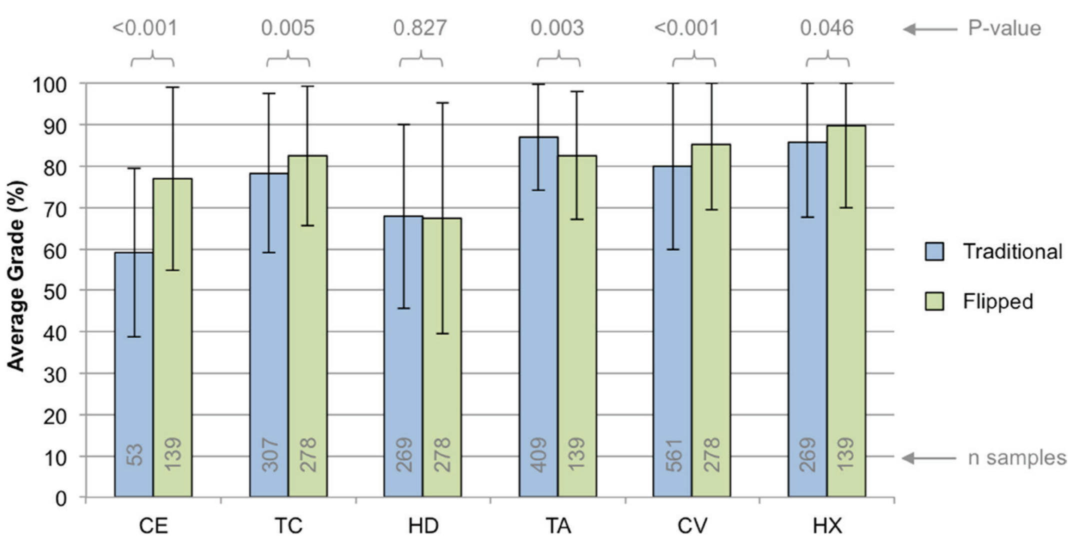


***Figure 3. Comparison between flipped and traditional student average grades for long answer exam problems for each of the six key concepts in Heat Transfer: Conservation of Energy (CE), Thermal Circuits (TC), Heat Diffusion Equation (HD), Transient Analysis (TA), Convection (CV), and Heat Exchangers (HX).***

earlier in *Thermodynamics*, another core mechanical engineering course and prerequisite for *Heat Transfer*. Although Energy Conservation is not terribly complex, extending its application beyond standard thermodynamic problems can be challenging for students. The flipped course allowed students more time to work on problems in class and extend the application of Energy Conservation to problems involving heat transfer and more complex systems beyond *Thermodynamics*. Because students are working on problem in class during the first week, we as the instructors can identify student conceptual errors and address them early in the semester.

Interestingly, students in the flipped course did not perform as well as their counterparts in the traditional course in 1 of the 6 key concepts (P-value = 0.003): Transient Analysis. There was no statistical difference in student performance in the key concept focusing on the Heat Diffusion Equation (P-value = 0.827). Most errors related to the application of the Heat Diffusion Equation stem from poor calculus skills and not setting up and defining a problem approach, regardless of whether a student was taught in the traditional or flipped course format.

**How do students perceive inverted instruction?**

At the end of the course, an online survey was conducted of students in the flipped course to better understand students' impressions of the flipped course and to understand how different course activities impacted their learning. As shown in Figure 4, students were asked to rate their confidence level (not confident to extremely confident) in approaching problems in specific concepts, which coincide with the weekly topic areas designed into the inverted course. As shown in Figure 5, students were asked to rate how effective or important (not effective to extremely

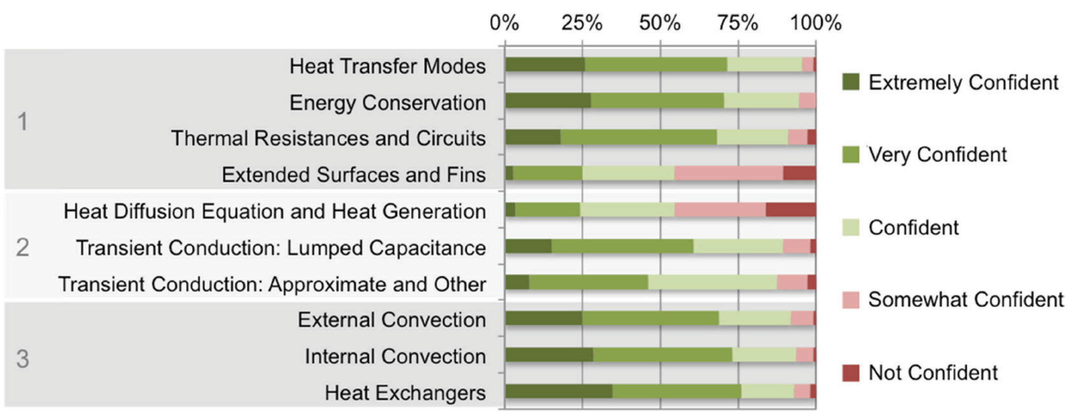


***Figure 4. Survey results showing percentage of students in flipped Heat Transfer and their perceived confidence level in ten Heat Transfer topics, separated into the 3 modules.***

effective) different aspects of the course were to their learning of the course material. Out of the 139 students enrolled in the flipped course, 112 students responded (approximately 80.6% student response).

### Student Confidence

As shown in Figure 4, over 90% of students in the flipped classroom felt confident to extremely confident in Heat Transfer Modes, Energy Conservation, and Thermal Resistances and Circuits in Module 1. These three topics make up 2 of the 6 key concepts in *Heat Transfer* (Conservation of Energy and Thermal Circuits). Additionally, over 90% of students felt confident to extremely confident in External and Internal Convection and Heat Exchangers – 2 more of the 6 key concepts in *Heat Transfer*. Notably, students in the flipped course statistically outperformed students in the traditional course in long answer questions (*Application*) in these 4 key concepts. In contrast, students in the flipped course felt least confident in the Heat Diffusion Equation and Transient Conduction. Interestingly, students in the flipped course statistically performed the same as or underperformed students in the traditional course. At the end of the flipped course, 57% of the students felt they had a deeper understanding of the material compared to other core undergraduate mechanical engineering courses. Peculiarly, 56% of the students felt they spent more time on course activities than in other technical courses.

### Student Perceptions on *Learning*

As shown in Figure 5, students valued the online content and, from survey comments, used the content in many different ways. Some students simply printed the lecture notes and reviewed, while other watched both or either of the *Pencasts* and *Slidecasts*. Students appreciated the ability to access the content on their own time and to be able to go back to the content at a later date. From the students perspective, the *Slidecasts*, *Pencasts*, and online example problems utilized in the flipped course ranked significantly more effective in their learning than assigned textbook reading (approximately 80% vs. 40% effective to extremely effective, respectively). Although over 80% of students found the *Pencasts* effective to extremely effective in their learning, many found them too long (each approx. 70 min) and suggested breaking them into shorter segments or investigating other ways of delivering online content to provide both detail and brevity. This is supported by research on online and blended learning and the length of online videos: Zappe and colleagues (2009) suggest videos be no longer than 20 minutes [44]. Additionally, shorter videos are rated as more engaging, where students watch them for more time and answer more post-video assessment problems [45]. Shorter videos make it easier for students to find particular explanations or discussion of content easily, and, they are more likely to be watched in full given attention spans.

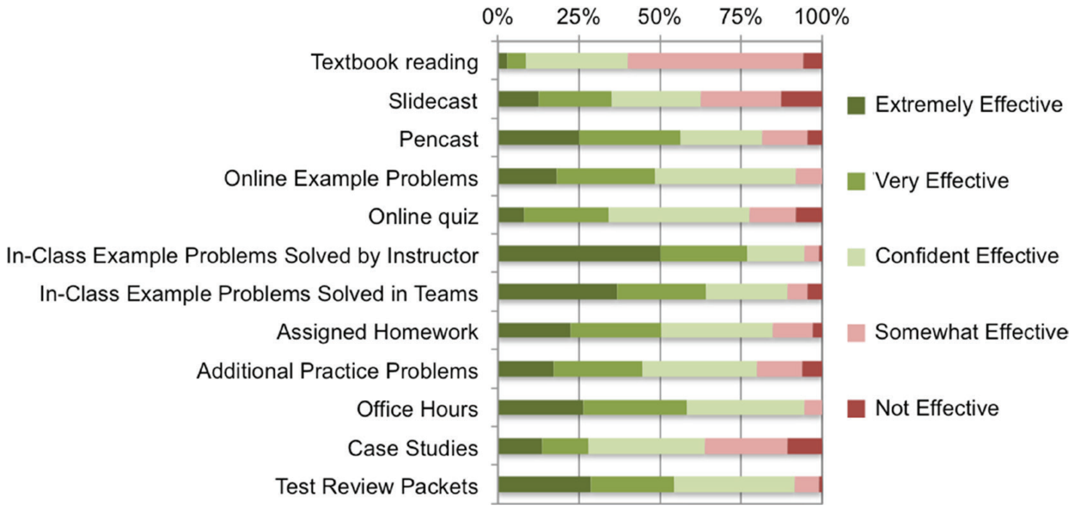


***Figure 5. Survey results showing percentage of students in flipped Heat Transfer and their perception of how effective various course activities were in their learning.***

The weekly pre-class online quiz was viewed as effective to extremely effective to student learning (approximately 75%) and was cited by students as one of the reasons they performed better in *Conceptualization* (multiple choice questions at the end of each module). In addition, an overwhelming 92% of the students felt the topic "highlights" provided during the first class of a weekly topic were helpful in reinforcing the online content.

Not all students embraced the concept of actively engaging in the online content before coming to class: Only 62% of the students felt they spent sufficient time with the online content before coming to the first class of a new topic and 66% felt prepared coming to the first class after reviewing the online content. Interestingly, 29% of the *Learning* quiz grades were 60% or lower, a strong indication that these students spent minimal to no time reviewing online content before coming to the first class. Contrasting the percentage of students who spent sufficient time with the online content (62%) and the percentage of students with online quiz scores above 60% (71%) with the percentage of students who found the online content effective to extremely effective in their learning (over 80%), suggests these students utilized the online content more effectively after the first class of a new topic.

### Student Perceptions on *Practice*

One of the main objectives for flipping the course was to free up more time in the classroom for discussion and problem solving. As shown from the student ratings in Figure 5, more than 90%

of the students in the flipped class perceived solving problems in the classroom, either solved by the instructor or in teams, as effective to extremely effective in their learning. These perceptions highlight an important distinction between flipped and traditional classrooms, as well as one of the advantages of the flipped course structure. Both types of in-class examples were cited by students as one of the reasons for better performance in *Application* (long answer exam problems at the end of each module).

A flipped course places more of the learning responsibilities on the students. While some students embraced and thrived with the higher expectation for self-learning, many struggled with the extra responsibility. This was most apparent in how students managed homework in the flipped course structure. In the first semester of the flipped *Heat Transfer* pilot, students were expected to solve problems using a logbook, where their effort was evaluated three times during the semester. Although the solutions were made available upfront, students were encouraged to struggle with the problems and only to consult the solutions if they needed guidance. However, approximately 45% of the students admitted to reviewing the solutions before struggling with the problems and 75% claimed to have waited until then end of the module to work on the problems. Unfortunately, less than 50% of students in the first semester pilot felt the homework was effective to extremely effective in their learning. Based on these results and suggestions from students, the logbook approach to homework was abandoned in the second semester in place of a weekly online submission of homework. Still, solutions were made available to the students upfront, and homework was graded based on effort rather than correctness. As part of the online weekly submission, students were required to complete a self-evaluation for each problem attempted and an online survey assessing their confidence level for solving problems from that week. By implementing these changes in the second semester pilot, over 80% of students perceived the homework was effective to extremely effective in their learning.

**Student Perceptions on *Extension***

The case study activities were intended to motivate learning and expose students to open-ended real world applications of *Heat Transfer* concepts. From survey results shown in Figure 5, over 60% of students thought the case studies were effective to extremely effective in their learning and, according to survey comments, many appreciated the connection to real world problems. The majority of students felt case studies helped them do better on related exam problems; others felt they spent too much time working on case studies. From survey comments, students appreciated the peer critique and feedback portion of the activity. Although the learning impact of this portion was not investigated in this study, nor quantified, from our perspective, the peer critique was extremely valuable as it exposed students, many for the first time, to the evaluation of others' work.

**Evolution of assessment for flipped Heat Transfer**

Classroom assessment needs to be aligned with course learning goals and objectives [46]. Assessment in flipped Heat Transfer is currently based on the same course learning goals and objectives as the traditional course. While the technical learning objectives have not changed between the flipped and traditional courses, the course frameworks have evolved. A number of resources point to designing assessments to align with learning objectives in a flipped classroom. In traditional courses, typical assessment includes some combination of class participation and/or attendance (generally, a small component of a course grade that accounts for a student showing up and being moderately involved in class), quizzes and exams to show mastery of lecture and reading material, and writing assignments/student presentations to show application and synthesis. When course frameworks evolve to include higher proportions of collaborative and active learning components, assessment must also evolve: Class participation becomes a much more substantive component of the course's requirements, such that simply expanding the percentage that participation contributes to a final grade would not be sufficient for assessing learning. Assessment needs to align with new course activities and expectations [47, 48], as exams cannot reliably evaluate processes and skills used during active learning activities. Active learning provides for numerous opportunities for formative assessment in contrast to traditional lectures, where there are few such opportunities [49–51]. Assessment of active learning can include a number of strategies, such as peer assessment [52], debriefing, observational checklists, student self assessment [22], student surveys to assess affective learning objectives such as perceptions, perspectives, and/or attitudes [53] as well as satisfaction [54], rubrics [55], and student presentations.

In flipped *Heat Transfer*, we have made efforts to evolve assessment from those typically utilized in traditional lecture-based courses to those recommended for flipped courses. In *Practice* events, students were asked to reflect on how they solved the problem and identify areas of weakness. Also, after submitting the homework, each student was asked to complete a simple online survey rating how confident he or she felt in his or her topical knowledge and solving various types of problems. Each survey question was mapped to a specific learning objective for the course. In *Conceptualization* and *Application* events, we debriefed in class the common errors that were observed in the quizzes and exams and encourage students to review provided solutions and compare their own work to understand where problems occurred. In *Extension* events, peer assessment was utilized, where student teams reviewed and assessed their peers designs and analysis on open-ended problems. While these peer assessments did not directly affect students' scores for the event, they were provided to the student teams as feedback. At the end of the course, we asked students to participate in a survey to better understand students' confidence level in approaching problems in specific concepts and how effective or important different aspects of the course were to their learning of the course material. While these assessment activities were intended to better align with flipped classroom learning objectives, the opportunity presents itself to investigate additional activities, such as utilizing observational checklists during team problems, incorporating self and peer assessment into a larger portion of activity scores, and emphasizing *Extension* activities in the students' overall course grade.

## CONCLUSIONS

Engineering faculty have the responsibility of introducing fundamental concepts to undergraduate engineering students, building and strengthening their technical competency, and ultimately preparing them to solve problems in an ever-changing global economy [56]. This proves to be extremely challenging given the number of content-rich courses students must complete in the undergraduate curriculum. Flipped instruction alleviates the challenge by enabling effective student learning outside of the classroom and providing opportunities for engaging activities inside the classroom. By utilizing inverted instruction in the core undergraduate mechanical engineering course, *Heat Transfer*, we showed students outperformed students in the traditional format of the course on conceptual multiple choice questions and closed-form long answer questions. Students in the flipped course found the electronic media highly effective in their learning and the majority found inverted instruction to be effective. The flipped course structure provided the opportunity to utilize open-ended case studies to motivate course learning, where the majority of students felt they were highly effective in their learning and appreciated the connection of the course material to real world problems. Overall, the majority of students felt they had a deeper understanding of *Heat Transfer* compared to other technical courses in the core mechanical engineering curriculum.

The flipped *Heat Transfer* course utilizes several components shown to improve student learning, each with their own contributions. The online content provides accessible lecture notes to all students and the online quizzes encourages students to review material beforehand. The way homework was handled in the course places the emphasis on students to learn and provides immediate feedback, which in turn encourages students to reflect on their understanding of the material. Working on problems in-class as a team provides opportunities for peer teaching and learning community building, as well as provides instructors the means to formatively assess how students are grasping course concepts. Through collaboration with their student peers, case studies help build student confidence in the application of course concepts and making assumptions and judgments about an open-ended problem. Whether combined or utilized separately, these components can be easily integrated into other core engineering courses. For instance, based on the positive outcomes described above, another traditional lecture-based core course in the mechanical engineering curriculum at our institution, *Fluid Mechanics*, has quickly adopted some of these unique components without investing the time required to fully flip the course. Here, *Fluid Mechanics* utilizes team problems and handles homework in the same manner as *Heat Transfer*, and also distributes comprehensive Pencast-like lecture notes to students.

The study reported here is limited in that it evaluates one academic year worth of student performance in the flipped course structure and compares it to two years worth in the traditional structure. However, by the time of publication, three years worth of students will have learned *Heat Transfer* in the flipped format, and one instructor not associated with this study will have taught flipped *Heat Transfer*. While not quantified in this study, the same general trends in student performance and perspectives have been observed and instructor satisfaction with the flipped format of the course remains positive. Notwithstanding, one area of future research will be to conduct a longevity study to elucidate trends in student performance and perspectives as well as instructor perspectives of flipped *Heat Transfer* over a longer period of time. Here, several factors could be studied such as student and instructor variability, and student performance trends as a function of grade point average, prerequisite course grades, gender, race, and ability, among others. The course could also benefit from optimizing the format of the online content, studying how the use of online content affects student performance, and investigating new course assessment strategies. While there are many approaches to engineering education, we believe flipped instruction can be easily implemented into core engineering courses and offers a practical and effective means of preparing todays engineering students for solving the problems of tomorrow.

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