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# Reconsidering the Course Format for the First Course in Thermodynamics

**Dr. Evan C. Lemley, University of Central Oklahoma**

Professor Lemley teaches thermo-fluid engineering and works with undergraduates to perform fluid dynamics research mostly focused on small scale flow problems. He currently is an Assistant Dean of Mathematics and Science and a Professor of Engineering and Physics at the University of Central Oklahoma; his home institution for over fifteen years. Previously, Professor Lemley worked as a mechanical engineer in the power industry. His Bachelor's degree is in physics from Hendrix College and his M.S.M.E. and Ph.D. were earned at the University of Arkansas.

**Aric M. Gillispie**
**Mr. Mathew Benton**

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**Abstract**

The first course in engineering thermodynamics is considered an above-average challenge by many engineering students. The mathematical rigor of the course is surely not the reason; the requirements of understanding substance properties and of developing methodical problem-solving techniques, likely, are major causes. We have modified our teaching methods in this course to an inverted or flipped classroom that employed less formal instruction techniques than the traditional lecture. Our smaller class-sizes (typically less than 30) allow for direct instruction by the instructor and the peer mentor, group problem-solving, and other techniques. This paper discusses observed effectiveness of using non-lecture techniques compared to a lecture-based course. The results of lecture-based courses were observed over several years. The results are compared to results in non-lecture-based courses, taught by the same instructor, in two offerings in Fall 2012 and Fall 2014. The Thermodynamics Concept Inventory has been used as well as overall performance on quizzes, projects, and exams. Other qualitative observations are also discussed. Positive effects were previously observed in the non-lecture course compared to the lecture course and this paper discusses our most recent observations.

## Introduction

The author (Lemley) teaches a junior level (first course) Thermodynamics course at the University of Central Oklahoma (UCO), which serves all engineering majors at the institution. This paper describes the author's most recent attempt to flip the classroom by having students devote time outside of class taking notes and studying lecture material, while working with the instructor on concepts and problem-solving during class meetings. The author initially implemented this approach to employ high-impact learning practices in the classroom.

## Flipped Classroom Pedagogy

This class was operated in "blended" fashion[1] where there was an online component (instructional media) and regular class meetings. The regular meetings did not include lectures, but instead involved one-on-one and group problem solving. The instructor's role in these meetings was to guide students, explain difficult and confusing concepts, and interact with each student individually or in small groups during each class meeting. The *flipped* format for this class was inspired by others that have taken this approach[2-4] and reported success. Although this idea is not necessarily new - to do something besides lecturing in the classroom - the idea has been recently reinvigorated due to the volume of content available online in every discipline. The modern idea of flipping may have been spurred by Mazur in 1991[5], where he introduced computer tools for introductory physics and predicted the increasing role of computer technology in providing hands-on tools for learning. In recent years flipped classrooms have been implemented in high schools and in universities[2-4, 6-7].

The ease of classroom flipping has increased due to amount of content online and the ability to produce customized content and instructional media using inexpensive technology. The author used a Livescribe™ Echo™ smartpen[8] to produce online lectures. The *smartpen* produces PPR (Play-Pause-Rewind) media. The pen uses a camera to capture written notes on a special grid paper (the grid allows software in the pen to decode the pen tip location as a function of time). In addition to capturing these images, the pen also contains a microphone to capture audio. Software, LiveScribe Desktop with Livescribe Connect™ [9], then allows the user to transfer the "pencasts" to a computer or to one of several online locations, including Google Docs[10] and Evernote[11]. One possible format for the pen output is in Adobe's portable document format[12] (pdf). Newer versions of the Adobe Reader supports multimedia. The resulting *pdf* contains a video that shows the recorded images from the pen's camera and the accompanying recorded audio from the pen's microphone. The student can control the playback of the pdf-movie. These media are potentially useful to students in understanding concepts by watching and rewatching, but especially in worked problems where the student can review assumptions or other parts of a problem-solving procedure as many times as necessary.

There has been much published regarding *active learning* and *discovery learning*, which derive mostly from the constructivist movement in psychology, e.g. see Phillips[13]. Entire curricula have been developed and certainly some classroom instruction has been affected by this movement. More recently, *pure* discovery learning has been called into question[14-16]. It has been demonstrated that guided *active learning* is effective, but it has also been demonstrated that for novices in a technical discipline, *passive learning* works well where students observe worked examples[16-17]. Flipping the classroom provides a way to include active and passive learning: students observe lectures and worked examples outside of class and actively solve problems in class in with instructor guidance.

**Implementation**

The thermo class discussed in this paper has been taught for several years as a traditional lecture course at UCO, by co-author Lemley. The structure of the class has been as follows: three 50-minute lectures per week conducted by the course instructor and one 50 minute drill session (includes a quiz and discussion of quiz problems) conducted by a teaching assistant over a 16 week period. Weekly homework is due during each drill session and graded and returned by the next drill session. There is a comprehensive final exam for the course. There is a design project, where students work in two person groups to design, analyze, and a report on a thermal system for power production. In the Fall 2012 and Fall 2014 course offerings, the course structure was kept the same *with the exception of the lectures and the portion of the grade that depended on taking notes outside of class.*

In the initial preparation for flipping the classroom, the lectures for the Spring 2012 offering of this course were recorded using a LiveScribe Smartpen[8]. The details of the production and use of these "pencasts" was presented in a previous paper[18]. The initial results of a flipped thermo classroom in Fall 2012 were described in a previous paper[19].

The thermo pencasts, which include a number of worked examples and cover issues from physics and engineering fundamentals to the application of the Second Law of Thermodynamics to devices and systems, were placed on a website so students could access them. Before each class meeting students were expected to watch and make notes on the pencasts appropriate for the weekly homework. Students were also encouraged to make notes from the course textbook.

One hope of structuring the course in this way was was to help students make good use of their time studying outside of class. The outside class activities were monitored by the instructor of the course using the students' documentation of their efforts in terms of notes and worked problems. A portion of the students' grades came from this documentation.

The author had one-on-one contact with each student during almost every class meeting asking about progress on lecture notes and the textbook, and answering questions. Students were assessed on the notes they had been taking and the progress they had made on homework. This assessment made up over 13% of the student's homework grade and was tracked in a course notebook binder where they kept all assignments and their notes on reading and pencasts. Often there were common misconceptions that the instructor could address for a group of students during class meetings. Other activities include students comparing notes on problems to see what they have done differently, students working problems independently, students working problems on the board for the entire class, individualized meetings regarding student projects. Students were actively problem solving throughout most class meetings.

**Concept Inventories**

The *concept inventory* was initially developed to assess gains made by beginning physics students in mechanics in the inventory called the *Force Concept Inventory*[20]. The use of concept inventories has now been extended into various engineering areas as seen on the ciHub (hosted at Purdue University[21]. The initial Thermodynamics Concept Inventory (TCI) introduced by Midkiff et al.[22] was developed in 2001, updated in 2006, and is now available to faculty through ciHub.org[21]. The TCI contains 32 questions that cover properties (25%), conservation of mass (9%), conservation of energy (First Law of Thermodynamics) (34%), Second Law of Thermodynamics (19%), and Work (13%).

The TCI was used as a pre-test and post-test in the Fall 2012 and Fall 2014 as described in this paper. The pre-test was administered during the first week of classes and the post-test was given in the last week of class. One common way to look at the pre-test and post-test data on concept inventories is to calculate a G*ain, G,* from the pre-test to the post-test as:

$$G = \frac{S_{post} - S_{pre}}{100\% - S_{pre}} \qquad (1)$$

Where $S_{post}$ and $S_{pre}$ are the post- and pre-test percentage scores, respectively.

**Results**

The results for Fall 2012 and Fall 2014 implementations of a flipped classroom for Thermodynamics at UCO, are compared to a traditional offering of this class from Spring 2011. Both courses had the author as the instructor and a very similar structure, with the exception of the flipped classroom approach. Very small changes were made to quizzes and the final exam, but these were very minor changes. Table 1 shows the difference in terms of grading structure of the courses.

**Table 1.** Grading Structure for Thermo classes discussed in this paper.

| | ***Spring 2011*** | ***Fall 2012*** | ***Fall 2014*** |
|---|---|---|---|
| ***Quizzes*** | 20% | 25% | 25% |
| ***Homework*** | 5% | 25%* | 12% |
| ***Course Notebook*** | - | - | 13% |
| ***Project*** | 25% | 25% | 25% |
| ***Regular Exams*** | 25% | -** | -** |
| ***Final Exam*** | 25% | 25% | 25% |

* *The Fall 2012 homework contribution included an in-class instructor review of student notes from the textbook and pencasts, as well as instructor assessment of progress on completing homework assignments.*

** *Regular Exams were not used in Fall 2012 or Fall 2014.*

As shown in Table 1 some differences were put in place in grading of these three classes. One difference in the Fall 2012 course was that homework was increased to 25% of the grade. In Fall 2014 the homework was adjusted to only be 12% of the grade, but 13% was officially dedicated to a grade on a course notebook. This grading scheme was not substantially different than the Fall 2012 scheme where 12.5% of the homework grade was assigned based on in-class checks of progress on pencasts and homework.

Regular exams were also not used in Fall 2012 or in Fall 2014. The change in not using regular exams starting in Fall 2012 was driven by the fact that quiz and scores regular exams scores over the last several course offerings have not been significantly different. In addition, quizzes give a very similar experience to exams; quizzes occur once a week and use at least two exam-style problems and take approximately 25 minutes to complete.

Differences were observed in the graded portions of the classes of Spring 2011, Fall 2012, and Fall 2014. These differences are shown in Table 2.

**Table 2.** Observed Differences Between Flipped and Traditional Thermodynamics Classes.

| | ***Spring 2011 Traditional (N = 23*)*** | ***Fall 2012 Flipped (N = 15*)*** | ***Fall 2014 Flipped (N=24*)*** |
|---|---|---|---|
| ***Quizzes Average(Std. Dev.)*** | 74%(10%) | 77%(10%) | 80%(14%) |
| ***Homework Average(Std. Dev.)*** | 75%(14%) | 92%(9%) | 92%(13%) |
| ***Project Average(Std. Dev.)*** | 81%(8%) | 88%(7%) | 88%(12%) |
| ***Final Exam Average(Std. Dev.)*** | 66%(11%) | 78%(13%) | 74%(18%) |

** These columns exclude students that did not drop the course but also did not participate in the Final, Project, Quizzes or Homework.*

In each of these classes there were some students that did not participate after the first several weeks, but did not drop the class. In particular, these students did not take the Final Exam, participate in a two-person group for the Project, or submit homework or take quizzes after a certain point in the semester. Since these non-participating students were not really affected by whether the class was traditional or flipped, they have not been included in Table 2.

The standard deviations of the results in Table 2 are not small and a strong statement cannot be made from any individual course component based on the data in Table 2. However, the trends are noticeable in terms of the improvement from Spring 2011 to Fall 2012. The improvement in the Homework and the Final Exam are noticeable if not statistically different.

The results for the Fall 2012 TCI were only available for 10 students due to students either missing the first or last drill sessions. The results in Fall 2014 for the TCI includes 22 students that took both the TCI pre-test and post-test. The *Gain* for the Fall 2012 class was 15% and was 17% in Fall 2014.

To further understand the subject area impacts on the TCI Gain, the percent improvement (not the gain) was calculated for each student for each of the subject areas contained in the TCI. The results for average percent improvement are shown in Table 3.

**Table 3.** Results for Fall 2012 and Fall 2014 *Thermodynamics Concept Inventory*.

| ***Subject Area (% of questions on TCI -- Number of Questions)*** | ***TCI Pre-test Percentage Correct +/- Percent Point Improvement (Percentage Improvement) -- Fall 2012 (N=10)*** | ***TCI Pre-test Percentage Correct +/- Percent Point Improvement (Percentage Improvement) -- Fall 2014 (N=22)*** |
|---|---|---|
| Properties (25% -- 8Q) | 48% + 11% (24%) | 50% + 9% (17%) |
| Mass Conservation (9% -- 3Q ) | 73% + 17% (23%) | 74% - 5% (-6%) |
| Energy Conservation (34% -- 11Q ) | 52% + 13% (25%) | 47% + 7% (14%) |
| Second Law (19% -- 6Q) | 45% - 0% (0%) | 29% + 23% (80%) |
| Work (13% -- 4Q) | 80% - 15% (-19%) | 65% + 11% (17%) |

In Fall 2012 improvements occurred in the areas of *properties*, *mass conservation*, and *energy conservation*. A slight drop occurred in the *second law* conceptual understanding and a larger drop in understanding of *work*. In the case of *work*, the students averaged an 80% initially and it makes up a small number of questions. The drops in performance on the *work* questions were primarily due to one question that asks the students to determine how much work will be produced by allowing two masses of the same incompressible solid materials to cool that start at different temperatures. Only one out of ten students got this question correct on the post-test, so the underlying concepts were not clear. Amazingly four out of ten students got this correct on the pre-test. This is likely just an anomaly in which several students guessed the correct answer on the pre-test. The lead author's detailed analysis of the problem reveals several issues with the question that certainly could confuse the students, for example: asking for work output when the solid material is incompressible. Discussing the related concepts and fleshing out the assumptions as a group in class could help overall with understanding, but we are not sure the TCI performance would improve on this question due to the wording.

In Fall 2014 there were improvements in all areas except *mass conservation* which started at 74% and represents the smallest percentage of questions (9%) on the test. The authors have looked in detail at the three (3) questions and answers that are mass conservation related on the TCI. A total of seven (7) students performed worse on these questions on the post-test. These students made more mistakes on two of the three questions. Both of these questions ask about what happens to air velocity as it flows 1) in an insulated diffuser and 2) in a heated pipe. The third question relates to whether a mass flow rate of air in a heated pipe stays the same or changes. The mass flow rate question was answered correctly by 77% of respondents on the post-test, while the air velocity related questions were answered correctly by 64% 68%, respectively, on the post-test. There appears to be more confusion about velocity than mass flow rate and the confounding issue of a gas with variable density likely also deepens the confusion. The lead author will carefully consider working more problems and having more discussions about how to proceed to analyze gas flow problems in the next instance in which he is teaching the class.

The improvement in understanding of Second Law concepts in Fall 2014 was of note in Fall 2014 where on average students got 23% more percentage points on the Post-test.

Qualitative observations were that as reflected in Table 2, students worked more on homework and in a more much more timely fashion than observed in the past. The one-on-one interactions helped better deal with issues in problem-solving, including the issue of how students approached problems. This appears to be indicated in the improvement in the Final Exam scores. In addition, the interactions with the instructor enhances student performance on the team-based projects compared to previous semesters and other courses.

After using a flipped methodology in several courses and looking at all evidence: quantitative and qualitative, the lead author thinks that the students' ability to learn new information and problem-solve independently were significantly improved as a result of flipped classrooms.

**Conclusions**

This paper describes a continuing effort to flip a Thermodynamics course. The course flip has been successful for two offerings of Thermo in improving grades on homework, projects, and final exams. In some cases the improvements are modest (final exam), but the improvement in quality of open-ended, team, design projects is significant. Some advantages of the flipped Thermo classroom as discussed in this paper are:

1. Flexibility during class meetings to work on problem-solving techniques and processes with students individually.
2. Ensure that each student understands thermo properties and help students that are struggling with properties.
3. Much more time for project discussions with project teams, which leads to significantly higher quality and more learning on projects (beyond the grade earned).
4. Students have to be engaged in class, since the instructor is talking to them usually multiple times per class meeting,
5. Students do not tend to delay homework until the night before it is due since the instructor is checking each student's progress on the current homework assignment each class meeting. Most students spend more time on homework than in traditional lecture classes because the instructor is asking them about their homework. Students are also less likely to copy solutions manuals on homework.
6. Students keep up with content by being asked to track their time and take notes on pencasts and reading.
7. Students tend to scour the pencasts and textbook for information - and even read their textbooks. This is because in many traditional lecture classes students assume the instructor's lectures contain everything that will be on the test. In the flipped classroom this assumption can't be made.

Despite the instructor's enthusiasm about flipped classes, the students don't always agree. Flipped classes, as described here, put more responsibility on the students and take more time and effort than a given student would typically spend on a traditional class. Because the lectures have been pre-recorded, some students may think the instructor is spending less time on the class. Of course the effort by the instructor is typically more. During class the instructor is not just reciting lecture notes, but instead dealing with many issues "on the fly," answering a wide variety of questions, and communicating with very different learners. There are usually student complaints about flipped classes. Flipped classes are different than what the students are used to and present them with more responsibility and more uncertainty. It is critical to have administrative support before making drastic changes in classes. The authors had strong support from their department chair and dean before implementing a flipped classroom, and it is recommended that other instructors also take this approach.

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