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# Implementing a Flipped Classroom in Thermodynamics

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## Abstract

"Flipping" the classroom is a somewhat new trend in education where students prepare by using their textbook, online content, or other materials before coming to class meetings. Flipping offers the possibility of class meetings being used for other activities such as problem-solving, rather than lecture. There have been some positive reports regarding this technique and the outcomes. This work describes the authors' efforts to implement a flipped classroom that could be compared to a previous course offering taught in the traditional way.

The author has implemented a flipped classroom in a small (<20) engineering thermodynamics course. The author has recorded a great deal of the course content in lectures and worked examples, and these resources have been put online allowing the possibility of a flipped classroom.

The results of this implementation of a flipped classroom show quantitative and qualitative differences in student outcomes compared to a previous offering of this course taught by the same instructor using a traditional lecture technique. The flipped version of the class performed better on homework and on the final exam than the traditional lecture class.


## Introduction

The author (______) teaches a junior level Thermodynamics course at the University of ______ (U_), which serves all engineering majors at the institution. This paper describes an attempt to *flip the classroom by have student's devote time outside of this class engaged in learning traditional lecture material and problem-solving using online media, then being engaged by the instructor on concepts and problem-solving during class meetings.* This approach was adopted to guide student's use of time outside of class and to employ high-impact learning practices in the classroom.

## Why Flipping?

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 federated content online and the ability to produce customized content and instructional media using inexpensive technology. The technology used for the purpose of flipping discussed here was a Livescribe™ Echo™ smartpen [8], which 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). The newest version of the Adobe Reader supports multimedia. The saved pdf actually contains a movie that shows the recorded images of the pen that is matched to the recorded audio from the pen. The observer can control the playback of the pdf-movie – hence the pen and related software allows creation of PPR instructional media. 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 U_, by the co-author (_______). 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 course offering, the course structure was kept the same *with the exception of the lectures and that there was a portion of the grade that depended on taking notes outside of class.*

In 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 by one of the co-authors (_______) in a previous paper [18]. The resulting pencasts are movie-like and include the written notes and audio created by the author. The resulting movies/pencasts may be paused and rewound (or fast-forwarded) so students can review the discussion in the pencast as many times as they like.

These 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 - all notes from the pencasts and the textbook were allowed for student use on quizzes and the final exam.

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 co-author (_______) had one-on-one contact with each student during each class meeting - asking about progress on lecture notes and the textbook, and taking questions. Students were assessed on the notes they had been taking and the progress they had made on homework. This assessment made up over 30% of their homework grade. 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* [19]. The use of concept inventories has now been extended into various engineering areas as seen on the *CiHub* housed at Purdue University [20]. The initial Thermodynamics Concept Inventory (TCI) introduced by Midkiff et al. [21] was developed in 2001, and updated in 2006, and is now available to faculty through ciHub.org [20]. 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 class described in this paper. The pre-test was administered on the first drill meeting (first week of class) and the post-test was taken during the last drill meeting (last week of class). One way to look at the data is to calculate a G*ain, G,* from the pretest 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 the Fall 2012 implementation of a flipped classroom for Thermodynamics at U_, are compared to a traditional offering of this class from Spring 2011. Both courses had the same 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. The grading structure was changed since the instructor felt that if regular lectures were not given, then he wanted to make sure the course content was studied. 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*** |
|---|---|---|
| ***Quizzes*** | 20% | 25% |
| ***Homework*** | 5% | 25%* |
| ***Project*** | 25% | 25% |
| ***Regular Exams*** | 25% | -** |
| ***Final Exam*** | 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.*

As shown in Table 1 some differences were put in place in grading between these two classes. The differences were as follows: homework was increased to 25% of the grade and regular 50-minute exams were not used throughout the semester. The reason for the change in homework grade was to ensure students spent sufficient time on course content, since lectures were not done in class. This contribution consisted of regular instructor reviews of each student's notes on the pencasts and the textbook; and an assessment of progress for the upcoming homework. This assessment was almost one-third of the homework score (or about 8% of the overall course grade). The change in not using regular exams 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. Considering the grading structures of each of these classes, students in Fall 2012 earn their grades more incrementally throughout the semester.

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

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

| | ***Spring 2011 Traditional (N = 24)*** | ***Fall 2012 Flipped (N = 17)*** | ***Spring 2011 Traditional (N = 23*)*** | ***Fall 2012 Flipped (N = 15*)*** |
|---|---|---|---|---|
| ***Quizzes Average(Std. Dev.)*** | 72%(14%) | 68%(25%) | 74%(10%) | 77%(10%) |
| ***Homework Average(Std. Dev.)*** | 73%(18%) | 83%(27%) | 75%(14%) | 92%(9%) |
| ***Project Average(Std. Dev.)*** | 77%(18%) | 77%(30%) | 81%(8%) | 88%(7%) |
| ***Final Exam Average(Std. Dev.)*** | 63%(17%) | 70%(26%) | 66%(11%) | 78%(13%) |

** These columns exclude students that did not participate in the Final or Project.*

In each of these classes there were some students that did not participate or minimally participated after the first several weeks, but did not drop the class. In particular, these students did not take the Final Exam or participate in a two-person group for the Project. The last two columns of Table 2 exclude the minimally participating students (one student in Spring 2011 and two students in Fall 2012). Since these non-participating students were not really affected by whether the class was traditional or flipped, the remainder of the discussion focuses on only the last two columns in Table 2.

Because of small numbers of students and the standard deviations shown in Table 2, 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 even if they are not demonstrably significantly different.

The results for the TCI were only available for 10 students due to students either missing the first or last drill sessions for Fall 2012. The *Gain* for the Fall 2012 class was 15%. Although this was somewhat disappointing, one student in particular who performed at the top of the class had dropped from a TCI pretest score of 69% to 59% did skew the Gain considerably. The Gain computed without this one student's score was 20%. This student was the senior-most student in the class and was taking this course after accepting a position as an electrical engineer. When interviewed, this student admitted that this style of flipped class did not fit his learning style well; the authors also think that students that have learned to thrive in traditional lecture environments may struggle with the flipped classroom approach.

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 *Thermodynamics Concept Inventory*.

| ***Subject Area (% of questions on TCI)*** | ***TCI Percent Improvement (original average%)*** |
|---|---|
| Properties (25%) | 32% (52%) |
| Mass Conservation (9%) | 27% (73%) |
| Energy Conservation (34%) | 32% (48%) |
| Second Law (19%) | -3% (45%) |
| Work (13%) | -18% (80%) |

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.

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 instructor interactions to enhance student performance on the team-based projects, made improvements to the students' reports for their projects, compared to previous semesters.

One other observation is that currently in many classes students often do not read their textbooks. In the Fall 2012 offering of this course students used and read their textbooks; students overall took responsibility of learning the basics of the material outside of class. The effects of this class on life-long learning were not assessed, but the authors think that the students' ability to learn new information and problem-solve independently was most likely improved as a result of this experience.

## Conclusions

This paper describes the first attempt by the authors to flip a Thermodynamics course. The course flip was a success in student improvement on homework, projects, and modest final exam improvement. The ability to more frequently discuss with students the process they use for problem-solving and how assumptions can be made and/or justified was perceived by the instructor to improve compared to traditional classes. Also the ability to discuss projects and provide guidance as students work in teams on the projects is not always possible in traditional classroom settings. Overall the time afforded by having students prepare before coming to class provides considerable flexibility and potential for class meetings; allowing the instructor to address issues for individuals and groups as they arise.

This paper does not offer conclusive evidence of the improvement due to a flipped classroom. The authors do not claim that all classes can improve by flipping, and in particular large classes may struggle with implementing flipped classes. However, the potential is great to take advantage of technology to allow the flexibility for in-class active learning activities.

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