IMPROVING PERFORMANCE IN THERMODYNAMICS: INTEGRATING LEARNING BY TEACHING PEDAGOGY

by

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ABSTRACT

JAMIE ANTHONY CAMPAGNI. Improving performance in thermodynamics: integrating learning by teaching pedagogy. (Under the direction of DR. PATRICIA TOLLEY).

Historically, Thermo is perceived to be the most challenging course in the MET Curriculum at UNC Charlotte. The complexity and difficulties of this course have contributed to the some of the highest DFW rates compared to any other courses offered within the MET program. One hypothesis contributing to high DFW rates is the pedagogy in which Thermo is taught, which is the foundation of this study.

Implementation of LBT in the spring 2014 offering of Thermo was deemed a success. The DFW rate in spring 2014 was reduced by 19 percentage points compared to the DFW rate in spring 2013, which exceeded the target of 10 percentage points. However, only cumulative GPA was a significant predictor of whether a student passed or failed the course. The semester in which students took Thermo was not a significant predictor. Students in the spring 2014 semester also exhibited statistically significant higher final exam averages compared to the 2012 and 2013 semesters. In general, students felt that LBT activities enhanced their learning and application of Thermodynamic concepts. Students had a very positive perception of LBT compared to traditional lecture in that 100% of students would recommend this teaching style to other students.

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CHAPTER 1: INTRODUCTION

Traditional teaching practice based on the textbook, chalkboard, lecture, homework, test paradigm has long been criticized as inadequate and inappropriate for student learning. Literature suggests that the use of teaching techniques that engage the students in the classroom have proven to be more effective in enhancing students' learning. Several pedagogies and techniques have been proposed in literature to help promote active learning and student engagement. Examples include Problem-Based Learning (PBL) (Carlson, 2005), software and technology based teaching programs (Martin & Mitchell, 2005) as well as student-centered learning (Townsend & al., 2008). Research shows that when exposed to active learning styles, "Students learn more when intensely involved in educational process and are encouraged to apply their knowledge in many situations" (Smith & al., 2005). This study evaluates the academic success of students exposed to an active learning pedagogy of learning-by-teaching (LBT) compared to those exposed to traditional teaching methods within a three credit, junior-level Thermodynamics course taught in a Mechanical Engineering Technology program in a large, public, urban, research university. Students' performance on semester tests, the final exam and, overall course grades was investigated. Success is defined as any student receiving a test or exam score of at least 70 and a final course grade of a C or better.

Thermodynamics, or "Thermo", is perceived to be the most challenging course in the MET curriculum at this institution. Thermo is also considered a "high risk" course, meaning it has a high DFW rate. The DFW rate is defined as the percentage of students who receive a final course grade of a D, F, or who withdraw with a grade of a W. Statistically, the DFW rate for Thermo is often one of the highest, approximately 50%, compared to other thermal/fluid science courses offered in the MET curriculum. Failure to pass the course causes the students to have to repeat it, often delaying graduation, as it is a prerequisite for senior level classes. Reducing the DFW rate allows students to stay on track with the outlined MET curriculum. In spring 2013 about 30% of students received a final course grade of a D or F, and another 25% withdrew from the course.

The importance of increasing student performance by reducing the DFW rate extends beyond the classroom. Thermo provides students with the concepts and fundamentals essential for jobs in the energy industry. Thermo is also key for students who are pursuing energy concentrations as they will be expected to apply basic Thermodynamic principles in future energy related classes. There are many factors associated with such a high DFW rate. In particular is the structure of the course. The course content is very conceptual, and frequently students do not have previous personal experiences to which they can relate course content. The concepts and fundamentals the students learn from day one are applied throughout the semester and constantly build on each other into more complicated and detailed applications as the semester continues. Based on previous semesters, students also often underestimate the workload and rigors associated with the course. Collectively, these and other factors such as working while attending school and the demand of other course work contribute to high DFW rates in Thermodynamics. One way to increase success and reduce DFW rates is to evaluate the way in which students are exposed to, assimilate, and apply course material. One area of particular interest is active learning.

Active learning is essential to the foundation of knowledge, especially in conceptually challenging courses such as Thermo. Pascarella and Terenzini (1991) reinforce the importance of active learning on the impact college has on students, by stating, “Simply put, the greater the student’s involvement or engagement in academic work, the greater his or her level of knowledge acquisition and general cognitive development.” Examples of active learning include application and evaluation questioning techniques, small group problem-solving techniques, as well as various reading and writing techniques. It is hypothesized that implementing active learning through LBT is a mean of reducing the high DFW rates and increasing overall student performance.

Data for this research was gathered from the 2012, 2013, and 2014 spring semester offerings of Thermo. Tests scores, final exam scores, incoming cumulative grade point average (CGPA), and final course grades were analyzed for all three semesters. For the 2014 semester, the semester in which the research was conducted, data from reflective writing assignments (RWA) and an anonymous end-of-semester survey were also collected. LBT was implemented in class and out of class in Supplemental Instruction (SI). The results of the study will be shared with various departments in the college of Engineering, college of Education, Center for Teaching and Learning, and the University Center for Academic Excellence.

1.1: Supplemental Instruction

SI was originally developed in 1973 by Deanna Martin at the University of Missouri-Kansas City (Webster & Dee, 1997.). SI is an out-of-class co-curricular program designed to enhance student mastery of course concepts and applications, and to encourage effective learning and study skill strategies (Webster & Dee, 1997). SI is typically targeted at particular high risk courses, rather than at high risk students (Marra & Litzinger, 1997). Thermo SI sessions generally consist of 4-5 sessions each 60-90 minutes long that meet weekly. The times and frequency of the meetings are determined by the students' feedback. The SI schedule is generated around the convenience of the students' class and work schedules whenever possible. SI sessions are conducted by an SI leader, one who has previously demonstrated mastery of course content and has received an A in the class. SI leaders develop sessions that focus on actively involving the students in in-depth exercises, and to challenge the students to actively think about the problem solving processes.

SI leaders often implement team-based exercises, problem-based learning strategies, active learning strategies as well as time management strategies, just to name a few. These strategies can be implemented several different ways. The SI environment is typically smaller than that of a general lecture environment which allows for more leader-student interaction and group activities. It is a learning environment in which students are continuously processing and applying course content obtained from lecture, textbook, and other course material.

In order to implement the LBT pedagogy, the structure of the SI sessions was altered. Unlike traditional SI models, the revised SI model used in this study requires the students to articulate and present their findings to their peers. Contrary to conventional

SI structure where the SI leader assumes primary responsibility for leading learning activities, the LBT version shifts the leader role to one of a coach or mentor and participants take turns leading various activities. Details and comparisons of different pedagogies are provided later. This difference in SI styles shifts the students' learning process from learning with the intent of being tested, to learning with the intent of teaching and explaining to their peers for the purpose of knowledge transfer and long-term retention. In theory, this style increases student engagement while enhancing their cognitive and metacognitive processing skills essential for success in Thermo.

1.2: Objectives and Scope

It is hypothesized that DFW rates will be reduced by enhancing student knowledge, acquisition, retention, and application of thermo concepts through LBT pedagogy. Student performance was evaluated throughout the semester. In theory, improving student performance (scores of 70 or higher) on semester tests and the final exam reduces course DFW rates.

LBT can best be described by a Chinese proverb from Confucius that states "Tell me and I forget; show me and I remember; involve me and I understand." The objectives of this research are to (1) enhance student performance as measured by an average score of 70 or higher on the final exam, and (2) reduce the course DFW rate by increasing students' knowledge acquisition, comprehension, retention, and transfer of Thermo concepts and application through LBT-based instructional and SI methods. The target is to reduce the DFW rate by 10 percentage points from 57% in spring 2013 to 47% in spring 2014.

Enhancing student performance as evidenced by higher test scores earlier in the semester is expected to decrease the high withdrawal rate. Daily homework, randomly administered quizzes, and three semester tests served as formative measures of student performance. For the purpose of this study, the efficacy of LBT is evaluated by two omnibus tests: average final exam score and course DFW rate. The study was designed to answer the following research questions:

1. Is there a difference in the average final exam score for students enrolled in Thermo in spring 2012, spring 2013 and spring 2014?
2. Is there a difference in the course DFW rates for students enrolled in Thermo in spring 2012, spring 2013, and spring 2014?
3. How does student academic preparation influence their performance in Thermo as measured by final exam scores?
4. How does the LBT pedagogy enhance student learning and application of Thermo concepts?
5. What are students perceptions of LBT pedagogy compared to traditional “chalk-and-talk” pedagogy?

The theoretical framework is discussed in Chapter 2. Specific methods of implementing LBT and evaluating its efficacy in terms of enhancing student learning and performance are discussed in Chapter 3. Quantitative and qualitative results are presented in Chapter 4 with interpretation and discussion of results provided in Chapter 5.

CHAPTER 2: LITERATURE REVIEW

Historically, Thermo is perceived to be the most challenging course in the MET curriculum at UNC Charlotte. The complexity and difficulties of this course have contributed to the some of the highest DFW rates compared to any other courses offered within the MET program. One hypothesis contributing to high DFW rates is the pedagogy in which Thermo is taught, which is the foundation of this study. Traditionally, Thermo is taught in a traditional "chalk-and-talk" lecture format. Within this conventional method, students are exposed to course content through a 75 minute lecture-based delivery twice each week. This pedagogy offers very little interaction between the students and the instructor, and between students and the course material. This is primarily due to a relatively large student enrollment (50-60 students) and the fact that the course is delivered in a large lecture hall.

The theoretical framework for this study is based on Bloom's Taxonomy of student learning, particularly within the cognitive domain, and is further discussed in the following sections. Information on various engineering pedagogies is discussed. Literature related to the implementation of SI within engineering curricula is also explored throughout this chapter.

2.1 Bloom's Taxonomy

There is ample research that suggests different pedagogies, particularly those constructed around an active learning foundation, prove to be more beneficial to the success of the engineering students than traditional lecture methods. In 1956, educational psychologist Benjamin Bloom developed a model to promote higher forms of thinking in education such as analyzing and evaluating, rather than strictly remembering facts (Seddon, 1978). The model consists of three domains of learning: cognitive, affective, and psychomotor. The cognitive domain, which will be the focus of this research, involves the knowledge and the development of intellectual skills in student learners. Many studies measure students' learning through the first four of the six levels of Bloom's Taxonomy of higher learning: knowledge, comprehension, application and analysis (Carlson, 2005). In the early 1990's a group of cognitive psychologists, led by one of Bloom's former students, reformed Bloom's classification levels relevant to the 21^{st} century educator and student. The revised taxonomy incorporated changes to the structure, emphasis, and terminology of the original version (Forehand, 2010) as shown in Figure 1.

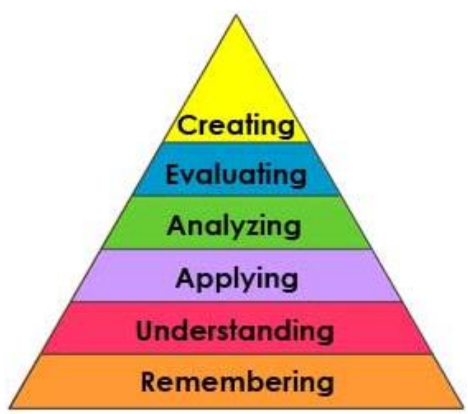

Figure 1: Revised Bloom's Taxonomy (Forehand, 2010)

For the purpose of this research, the applying and analyzing levels will be the areas of focus. Blooms Taxonomy is hierarchal in nature, meaning that if a student is performing at the "application" level, he/she has mastered the material at the "understanding" and "remembering" level. This is important to note when evaluating the level at which Thermo students are expected to perform. Due to the difficult nature of Thermo, students are expected to perform at the analyzing/evaluating levels of the cognitive learning domain. They must analyze a problem statement by applying basic concepts, assumptions, and equations, then solve the problem and evaluate their solution by making judgments and checking their work. In order to succeed at the analysis and application levels, students must first be proficient in the lower order thinking skills such as remembering and understanding. It is at these levels that students are expected to recognize, recall, infer and interpret thermodynamic fundamentals and principles. The research outlined in the following sections also focuses on analyzing these levels of student learning through various pedagogies.

2.2: CHAPL Pedagogy of Engagement

Research has shown that students are more susceptible to retain and apply concepts when exposed to active learning classroom environments. According to Golter, "learning improves with increased involvement in the educational process" (Golter & al., 2005). They realized that the teaching paradigms needed to be altered in their Fluid Mechanics and Heat Transfer classes to help bridge the gap in differences between how students learn and traditional deductive teaching styles.

Deductive teaching styles are those in which a structured presentation is used to convey general concepts by defining then providing examples and illustrations that enforce the concepts presented. Deductive teaching styles are more teacher-centered and offer students limited interaction with course material. Inductive teaching styles however, are more student-centered and provide students the opportunity to reflect and become more deeply involved with course material. Examples of inductive learning methods include problem-based learning, project-based learning, or any form of learning that utilizes a collaborative or cooperative learning environment (Prince & Felder, 2006).

With the help of other faculty members within the Engineering Department at Washington State University, Golter and his colleagues created their own modern learning pedagogy dubbed CHAPL. This alternative teaching style combined four pedagogies: Cooperative learning, Hands-on learning, Active learning, and Problem-based learning (CHAPL).

They applied the active learning approach through brief, small group exercises designed for conducting projects and solving homework problems. There was little conventional lecture used in the classroom setting, but instead the instructor acted as a mentor to the groups, stepping in only to help resolve group conflict. As part of the problem-based learning pedagogy, Golter and his colleagues assigned various open-ended design problems to help stimulate the knowledge and application of course principles. The faculty measured success of the new approach through positive feedback obtained from the students on end-of-semester surveys and skill assessments on semester tests evaluated by the professors. They then compared these surveys and assessments to those of a previous semester where students were exposed to a traditional, deductive style lecture environment. Class enrollment and classroom types were the same for all semesters compared in the study. They found that in general 60% of students preferred the CHAPL pedagogy versus the conventional lecture. Gotler and his colleagues also concluded through course surveys that students exposed to this method were more knowledgeable about course concepts.

2.3 Problem-Based Learning (PBL)

Similar to Golter and his colleagues, Carlson (2005) applied a PBL approach to his Thermodynamics class at the Rose-Hulman Institute of Technology (RHIT). This method was applied in a more casual atmosphere than conventional lecture environments where the students were organized around tables, rather than rows and desks. Carlson (2005) defined PBL in his course as "a learning process where the desired course outcomes are achieved through well designed, open-ended real life problems." Similar to Golter and other research, Carlson (2005) divided his class into small groups consisting of 3-5 students each. Prior to the class meetings, the students were told to review material from the textbook in preparation for the content they would be exposed to on the in-class problems. This forced to students to learn the material without the use of direct teacher-led lecture. These groups were assigned the task of forming solutions to complex, in-depth problems assigned by the professor. In-class problems were carefully selected so that the students had to reflect and build upon their previous knowledge. Here again, the role of the professor in this classroom environment was more of a resource/tutor, guiding the student teams rather than instructing the teams, as is the same with the LBT pedagogy.

The efficacy of PBL in the RHIT study was assessed through projects, semester exams, and various project reports. On all three assessments, Carlson (2005) concluded that there was not a "discernible difference between classes taught using PBL compared to lecture" in terms of overall course grades (Carlson, 2005). However, lecture based delivery methods proved to be *least* effective when analyzing application and analysis skills throughout his assessments. In contrast, the PBL approach encouraged the students to become independent learners and helped strengthen communication skills through group-based work. Students improved their analytical skills on course tests better from PBL than from watching the instructor solve the problems in lecture. One interesting finding was the negative feedback from students subjected to the PBL environment. Carlson (2005) determined from this that the students had not yet developed the necessary leadership and organizational skills that this pedagogy requires. Also, the students did not like the idea that they had to learn the course material on their own.

The fact that the analytical skills of students exposed to the PBL pedagogy were noticeably better than those exposed to a traditional lecture makes this an appealing option. However, one should take caution when structuring a course solely around this method due to negative feedback obtained from students in the RHIT study. The negative feedback could be due to the fact that they were not sufficiently exposed to this type of learning environment previously. When using the PBL pedagogy, it may be best to use it in conjunction with a primary or more familiar pedagogy tailored to the liking of the students' learning preferences.

Contrary to Carlson's findings, Rojter (2009) experienced success relative to positive student response when PBL was implemented in an Engineering Material Science class. Rojter's class was structured similar to that of Carlson's Thermodynamics class, in that the students were grouped into teams and assigned open-ended design based problems. Rojter (2009) focused more on the design aspect within the Material Science course rather than assigning in-depth analytical problems. Final course grades and end-of-semester surveys were used to evaluate the efficacy of PBL on student success. "Despite the subject complexity and the intense demands of the subjects, student response was highly positive" (Rojter, 2009). The only negative feedback from this research was similar to that seen in Carlson's (2005) study. In both instances, negative feedback was attributed to the unfamiliar learning style as well as undeveloped study skills and time commitment. Both instructors noted that preparation for lectures utilizing PBL was significantly more time consuming than preparing for conventional lectures. This is an important factor that should be taken into consideration when considering the use of the PBL.

2.4 Learning by Teaching (LBT)

Another pedagogical approach to active learning is Learning-by-Teaching (LBT). According to Carberry and Ohland (2012), "placing the student in the role of the teacher permits the student to benefit from the activities implicit in teaching and simultaneously allows for the teacher to play the more effective role of coach or guide". They compare the works of various engineering educators who have successfully implemented this pedagogy in engineering environments. Through their research, Carberry and Ohland assessed variables such as preparation, presentation, and assessments of the student performance when LBT was implemented.

They concluded through various studies that integrating LBT allowed the student to interact with course content and peers in a way that enhanced deeper learning and stimulated positive attitudes towards engineering concepts thus implying LBT methods provide an opportunity for students to "learn how to learn". While traditional lecture is more efficient in increasing the amount of material delivered to the students, it also imposes a limit as to what the students actually learn due to the limited active engagement students have with course material. It is worth noting that Carberry and

Ohland found that LBT is effective when performed in a group based environment. Social interaction between the teacher and the learner was found to be beneficial when the LBT pedagogy was implemented.

These findings suggest that LBT pedagogy may be effective when placing the student in the role of the teacher. The challenge of implementing this method comes with the reduction in the amount of course content delivered in a standard classroom environment, particularly a large lecture hall. Since SI is not structured to teach new material to the students, but rather reinforce the material covered in lecture, this makes the LBT pedagogy a logical fit to implement within the SI model. The application of LBT in lecture is more difficult given the time constraints and introduction of new concepts and applications. Time is the biggest challenge instructors face when implementing any teaching style.

2.5 Comparison of Engagement Pedagogies

When deciding which pedagogy is best suited for student learning, there are many factors that need to be taken into consideration. Since students learn in various ways, it is important to implement an instructional method that best suits the learning objectives of the course with the learning styles geared towards engineering students. As indicated in Table 1, traditional lecture, PBL and the CHAPL method are best implemented for classes with larger student enrollments.

Table 1: Comparison of pedagogies

	Lecture	LBT	CHAPL	PBL
Class Size	~ 50	30 – 40	30 – 40	15 – 30
Group Size	1 – 3	≥ 2	2 – 4	3 – 4
Role of Teacher	Instructor	Mentor	Facilitator	Facilitator
Pre-Requisite Knowledge	No	Yes	Yes	No
Focus	Instructor	Student	Can be shared	Shared
Examples/Activities	Instructor completes in class exercises	Peer-led learning activities	Mixed-method approach	Open-ended problem solving
Positives	Can cover vast amount of material	Students learn from peers rather than a passive lecture	Students are exposed to multiple learning styles	Forces students to become self-learners
Negatives	Little time for active engagement with course material	Time commitment and challenging for students	Does not focus on one specific pedagogy	Hard to implement due to increased time demand

Given relatively large enrollments and the vast amount of material covered in Thermo, traditional lecture has been the preferred teaching style at most engineering institutions. However, traditional lecture does not provide students the opportunity to actively engage with course material. It is a very passive form of learning. During traditional lecture, students have little, if any, opportunity to develop metacognitive skills as they merely copy instructor lecture notes rather than actually thinking about and reflecting on what they are writing and learning.

In contrast, proper implementation of the LBT and PBL methods allow students to engage with course concepts through peer-led learning activities and/or open-ended problem solving sessions. This in turn enhances metacognition when the LBT, PBL and the CHAPL pedagogies are implemented versus traditional teaching methods.

Metacognition is often defined as “thinking about thinking” and consists of metacognitive knowledge and metacognitive regulation (Livingston, 2003). The term is best attributed to Stanford professor John Flavell who defines metacognitive knowledge as “knowledge or beliefs about what factors or variables act and interact in what ways to affect the course and outcome of cognitive enterprises” (Flavell, 1979). Metacognitive knowledge is essentially an individual’s knowledge of his/her own learning processes and can be evaluated through quantitative measures such as tests and exams, or monitored through qualitative such as reflective writing assignments.

Metacognitive regulation can best be described as a learner implementing cognitive activities to achieve a learning goal. For example, one may read a paragraph from a textbook, with the goal of understanding the content of the text. After reading, the student may question themselves about the concepts within the text. Naturally, if the concepts are not understood, the student will re-read the paragraph until the learning goal of understanding the paragraph is met. This form of self-questioning is a common form of metacognitive regulation. Metacognitive skills are enhanced when students transfer and apply their skills to new applications which can be implemented through LBT.

LBT activities also help facilitate metacognition because students reflect on their problem solving process and analysis skills used to complete the assigned tasks. Having the students audibly articulate their problem solving process, unlike the PBL pedagogy, also reinforces knowledge transfer and promotes long-term retention of thermodynamic concepts. This is important due to the fact that Thermo in general and Thermo tests in particular challenge students' higher order thinking skills, such as synthesis, analysis and evaluation, as well as assimilation, comprehension, and application skills. Therefore it is important to implement a learning style that promotes students' knowledge transfer skills. The LBT and PBL pedagogies often implement some type of team/group based activities which in turn causes students to learn from one another thereby expanding individual and collective knowledge.

Working in groups enhances articulation, problem-solving, and knowledge transfer skills among students as they are placed in an active learning environment. This allows students to collaboratively demonstrate their knowledge amongst their peers. The LBT method enhances metacognitive skills by allowing the students to reflect on and present their problem solving processes, and demonstrate their knowledge of course concepts to their peers. This provides students the opportunity to learn from peers in addition to copying example problems provided by the instructor during conventional lecture.

While there are plenty of positive aspects about the LBT, PBL, and CHAPL pedagogies, there is one negative aspect that all three pedagogies have in common, and that is the time required to develop and implement and the possibility of negative feedback from students. Typically, Thermo is structured around 75 minute lectures that meet twice a week. The fast-paced course allows limited time for example problems to be worked in detail by the instructor. Frequently students cannot complete a worked example during class due to the length and complexity of the subject matter. This requires the instructor to post solutions that may lack detail or annotations. Restructuring lectures to allow for students to complete and present problems gives them a hands-on approach to engage with new material which they can apply to future homework assignments and tests. For the purpose of this research, the LBT method was the pedagogy of choice.

Given the time requirements for a pedagogy as involved as LBT and a course as rigorous and conceptually challenging as Thermo, implementing LBT into the traditional lecture format was a challenge for the student researcher and instructor. Despite the additional time needed for lecture prep and in class activities, LBT was carried out with alterations to the current curriculum. The following section summarizes the methodology and implementation of LBT within Thermo.

CHAPTER 3: METHODOLOGY

The study was conducted at a large, urban, public, research institution in the heart of the Southeast. Learning-by-Teaching (LBT) pedagogy was implemented within Thermo lecture and Supplemental Instruction (SI). The sample included students enrolled in Thermo in spring 2012, 2013, and 2014. These semesters were selected due to the fact that the instructor and SI leader were the same for all three semesters. Students from a variety of backgrounds and ethnicities enroll in Thermo. The ethnic diversity often poses a greater challenge for students whose first language is not English in terms of comprehending and applying challenging Thermo concepts. Students' diverse educational backgrounds ranged from transfer students, non-traditional students, Mechanical Engineering Science majors who transferred to Mechanical Engineering Technology, to those who had been part of the Engineering Technology (ET) program since their freshman year.

In spring 2012, 2013, and 2014 Thermo was held on the same days and times. The course instructor and SI leader were the same for all three semesters. . Results of student performance from the spring 2014 semester in which LBT was implemented were compared to the traditional lecture and SI offerings of the other two semesters. LBT was deemed successful if DFW rates were reduced by at least 10 percentage points compared to traditional "chalk and talk" pedagogy.

3.1 Study Participants

Historically, about 50-60 students enroll in Thermo in the spring semester. For the semester in which the research was conducted, spring 2014, only 27 students enrolled in the course at the time of census in January 2014. The reason for the low enrollment is likely due to a new pre-requisite that was implemented in fall 2013. Students who did not pass Fluids with a C or better were not eligible to take Thermo unlike previous semesters in which a D was considered passing. In addition, many students choose to take Thermo during a five-week summer session.

Prior to implementing the study, students were informed by the student researcher of the purpose of the study, how it would be conducted, that their participation in LBT activities in class and SI was voluntary, that individual performance on graded assignments and tests was confidential, and that only de-identified, aggregated results would be reported. Most of the students were familiar with the student researcher prior to taking Thermo because of his role as an SI leader. Students were informed that if they chose not to participate in the study they would not be penalized. In fact, their decision would not be known until after final grades were posted. The SI leader and instructor left the room and a faculty member unaffiliated with the study distributed consent forms and retained them in his office until final grades were posted. Only one of the students from the research group chose not to participate in the study. His data were removed from the dataset prior to analysis and all other participant identities were protected. Consent was not required from participants in the previous two semesters because most of those students had graduated and were no longer affiliated with the university at the time the study was conducted.

3.2 Classroom Setting

Prior to spring 2012, Thermo was taught in a small conventional style classroom that accommodated approximately 50-60 students. The seating arrangement in the classroom was very constrained and the small desks and chairs made it extremely difficult for students to lay out course materials needed for lecture and tests. Due to the small seating/desk space, students often had to balance books, handouts, and other material in their laps while attempting to write lecture notes. There was little room for students and instructor to move about or engage with one another.

Since spring 2012, Thermo has been taught in a large auditorium style lecture hall capable of seating approximately 100 students that offered a more conducive learning and educational research environment. The room consists of five rows of tables with attached swiveling chairs that span the entire width of the lecture hall. These large tables provided ample space for students to lay out course material and are large enough to accommodate small group activities. Lining the lecture hall are eight large dry erase white boards. Having a large number of dry erase boards provided the students and instructor additional work space for completing LBT activities. Most importantly, the number of white boards allowed the researcher to better observe the students' problem-solving strategies during LBT activities.

3.3 SI Setting

In spring 2009 the Department of Engineering Technology and Construction Management attempted to address the high DFW rate by implementing Supplemental Instruction (SI). While participation in SI at this institution is not mandatory, it is strongly recommended by the professor and the SI leader, as well as advocated by the Center for Teaching and Learning and the University Center for Academic Excellence.

SI sessions were held in a different style classroom tailored more for group-based learning. Seating arrangements consisted of eight tables each with four chairs. SI sessions were structured to integrate LBT and also served as a research environment for the student researcher who was also the SI leader.

Typically, SI sessions are structured to reinforce course content rather than teach new material. Sessions are led by an SI instructor, who is a student who has displayed mastery of course content and received a high final course grade, usually an A, for the selected SI course. The student is trained as a SI instructor by attending weekly meetings with a program coordinator and other future SI leaders throughout the semester. During these meetings, the SI leaders are taught various teaching styles which are then implemented in 4-5 one hour SI sessions held each week, as in the case with Thermo. These meetings also provide leaders with skills and techniques essential to developing students' learning and strategies for mastering course content within SI sessions. The program coordinator, or his/her representative, observes one or more SI sessions as part of the training and provides feedback to the leader. The SI leader sits in on the course lectures for which SI is being offered. The SI leader and course instructor meet throughout the semester to discuss pertinent feedback from the SI sessions. After completing a semester of training and implementation, the SI leader is then certified in the model.

3.4 Integration of LBT into Lecture

In order to integrate LBT within lecture, the instructor was required to adjust the 75 minute lecture format. The LBT approach included a 50-60 minute lecture followed by small teams of students working for the remainder of the period (15-25 minutes) at the whiteboards. Students were then required to present their group findings to the class.

LBT activities ranged from conceptual worksheets that required students to list assumptions and equations pertaining to various Thermo concepts, to word problems designed to enhance collaborative learning, problem-solving, and knowledge transfer. Each LBT activity challenged students' knowledge, comprehension, application and/or analysis skills needed to succeed in the course. In total, seven LBT modules were implemented: five group-based and two individual.

Each LBT module was created to measure students' performance and learning outcomes relative to that week's lecture material. The objective of the module and any prior knowledge required for completion of the specific module were clearly articulated. The majority of modules were designed to be completed in groups of 3-4 students. Groups were encouraged to work at one of the eight whiteboards surrounding the lecture hall. This allowed for the researcher to easily observe and record students' behaviors, interactions, questions, and comments. Upon successful completion of each module, one student from each group was appointed to present the group findings and solutions to their peers. Since there may be more than one way to solve a given problem, students were able to see and learn various approaches to solving the same problem. Students also realized that concepts with which they were struggling were also difficult for their peers. Students were provided a copy of the LBT module for their records. Figure 2 below is a

LBT module pertaining to ideal gasses and was designed to be completed in groups within 15 minutes.

ETME: 3143
SP 2014
Learning by Teaching

Module #3

Objective:
The students will work in groups to collaboratively demonstrate their understanding of the ideal gas model. The students will apply their knowledge and understanding of thermodynamic properties associated with ideal gases. Students will be able to solve for unknown variables such as pressure and work using the ideal gas law. Students will also be able to correctly model a P-v diagram for an ideal gas.

Learning Outcome:
Students will be able to: (a) model an appropriate P-v diagram where air is the working fluid, (b) identify assumptions associated with the ideal gas model and, (c) apply a basic understanding of ideal gas laws/equations to solve for unknown variables.

Prior knowledge required:
This activity will be administered to the students after they have been exposed to the ideal gas model. Students will need a basic understanding of the thermodynamic properties associated with ideal gasses. Prior to this module being implemented, students should also understand how to use and apply the thermodynamic tables for ideal gases, as well as assumptions germane to ideal gases.

Activity (15 minutes):
Air is compressed adiabatically from P_1 = 1 bar, T_1 = 300 K to P_2 = 15 bar, v_2 = 0.1227m^3/kg. The air is then cooled at constant volume to T_3 = 300 K. Assuming ideal gas behavior, and ignoring kinetic and potential energy effects solve the following: Sketch the two-step process on a P-v diagram making sure to include lines of constant temperature. Calculate the work for the first process and the heat transfer for the second process, each in kJ/kg of air. Make sure to list all assumptions pertinent to this problem.

Measure(s) of Performance:
1) Students successfully modeled a P-v diagram for an ideal gas and included lines of constant temperature.
2) Students successfully applied the ideal gas law to solve for unknown variables such as temperature, pressure, and/or volume
3) Students demonstrated appropriate use of ideal gas relationships (i.e. $\Delta u = C_v * \Delta T$) to solve for unknown variables such as work and heat transfer.

Figure 2: LBT module for ideal gasses

Prior to this module being administered, students were expected to have a basic understanding of Thermodynamic properties associated with ideal gasses as well as the use of Thermodynamic tables pertaining to ideal gasses. After successful completion of the module, students were expected to model a pressure-volume diagram with ideal gas as the working fluid. Students were also expected to properly apply assumptions, ideal gas laws, and energy relationships to solve for unknown variables such as work and heat transfer.

The objectives, learning outcomes and measures of performance were unique for each module. During completion of the modules, student performance and participation were observed and recorded using the template in Figure 3.

Date	Student Name	Attendance (SI/Lecture)	3 = Exceeds Expectations 2 = Meets Expectations 1 = Does not Meet Expectations				Questions Asked/ Comments Made	Notes
			Engagement/ Productivity	Quality of Work	Attitude/ Interest	Performance		

Figure 3: Student observation template

Students' behaviors, interactions, questions, and comments were also observed and recorded. After the completion of each module, the student researcher provided the class with a synopsis including feedback and recommendations focusing on the variables outlined in student observation template. This allowed the researcher to make sure that the modules were beneficial to student success and any learning gaps observed could be addressed in future LBT modules and other lecture and SI activities.

In addition to group-based LBT modules, there were also two individual LBT modules administered throughout the course of the semester. The purpose of the individual modules was for students to reflect on that week's lecture material and apply that knowledge to a specific activity. The individual LBT modules were designed to promote metacognitive regulation, or the process of "thinking about thinking". Enhanced metacognitive regulation allows students to direct the thought and learning processes in a way that strengthens comprehension of Thermodynamic concepts. The individual LBT modules were intended to challenge the students' understanding, analysis, and synthesis of concepts. The intent was for students to reflect on what was asked in the assignment compared to the lecture material covered that week without relying on assistance from group members, instructor or the teacher assistant. An example of an individual LBT module can be seen below in Figure 4.

ETME 3143
Spring 2014
LBT #5 (2/26/14)

Classify the following processes of a closed system as *possible,* or *impossible.* In most cases, there is more than one right answer. Justify your answer and describe the type of system. For example,

- Is the system adiabatic? Is heat added or rejected?
- Is the system operating reversibly or irreversibly?

	Entropy Change of the System	Entropy Transferred by Heat	Entropy Produced within the System	Possible or Impossible	Process Description/Justification
A	>0	0			
B	<0		>0		
C	0	>0			
D	>0	>0			
E	0	<0			
F	>0		<0		
G	<0	<0			

Figure 4: Individual LBT module

This module was assigned at mid- semester once students were introduced to the 2nd law of Thermo. Students were asked to evaluate seven scenarios related to entropy production of a closed system and the 2nd law. In most cases, there was more than one right answer for each scenario. Students were asked to list all possible solutions to each scenario with a justification and description of the processes they listed.

3.5 Integration of LBT into SI

The structure of the SI sessions was also altered in spring 2014 to incorporate the LBT pedagogy. Unlike other problem-based learning SI models, the revised SI model used in this study required the students to articulate and present their findings to their peers. Contrary to conventional SI structure where the SI leader assumes the primary responsibility for leading activities, the LBT version shifts the leader role to one of a coach or mentor where participants take turns leading various activities. The SI leader facilitates rather than instructs. This is achieved through peer-based activity sessions where the attendees are assigned a specific topic or problem statement. The students have approximately 20-30 minutes to research and solve the assigned problem or topic, then present their processes and findings to the SI attendees. During this time, the SI leader mediates the group ensuring proper process and appropriate findings. The students are encouraged to work in collaboration with their peers throughout the problem solving process. They look to the class for assistance if a problem arises, rather than defaulting to the SI leader for assistance like traditional SI sessions. If a resolution cannot be achieved via the teamwork of the attendees, the SI leader intervenes and takes the role of instructor until the issue is resolved. When the issue is resolved, the SI leader immediately defaults back to the mentor/coach role. The remainder of the session is dedicated to students presenting their findings/problem-solving process to their peers.

Depending on the number of attendees, this approach can be administered individually or through group exercises consisting of no more than four members. If the group approach is used, the SI leader still assumes the roles and duties outlined above. Since the students work in groups, they present their assigned problem and solution in groups to their peers. It is up to the discretion of the group on how the material is presented, but every member must actively participate. The duration and frequency of the LBT SI sessions are consistent with traditional SI sessions offered in the past. The efficacy of LBT can also be translated to other courses for which SI is offered.

This difference in SI styles shifts the students' learning process from learning with the intent of being tested, to learning with the intent of teaching and explaining to their peers for the purpose of knowledge transfer and long-term retention. In theory, this style increases student attention while enhancing their cognitive processing skills. The LBT method demonstrates active learning through verbalization of course material allowing the students to communicate in an active manner, rather than passively deciphering what is being lectured in traditional learning environments. The LBT method also enhances the metacognitive skills of students by making them aware of their strengths and weaknesses through articulation and reflection of their problem solving processes. Also, LBT enhances student communication skills, particularly with respect to technically challenging subject matter, when they are required to present material to their peers.

3.6 Quantitative Measures of Student Learning

Throughout the semester, students conveyed their knowledge of Thermodynamic concepts and principles via homework, quizzes, three tests, a team project, and a cumulative final exam. Standard statistical analyses were used to compare spring 2014 test averages, final exam averages, and DFW rates to those from spring 2012 and 2013 semesters. Descriptive statistics, chi-square, Analysis of Variance (ANOVA) and logistic and linear regression tests were conducted using Statistical Program for Social Sciences software (SPSS, ver. 20). Students' cumulative GPA (CGPA) at the beginning of the semester in which they took Thermo was evaluated as a proxy for academic preparation and to correlate with performance in the course. Class averages on each semester test were compared among the three semesters to determine if LBT did in fact affect student performance. DFW rates were also evaluated for the three spring semester offerings of Thermo. Students receiving a grade of 70 or higher on the final exam and a C or above on the overall course grade were considered successful. For the purpose of this study, the final exam score and DFW rate are the omnibus tests.

After the results of the first test, and each test thereafter, students that were considered at risk academically were encouraged to attend SI if they had not already participated. The aim of implementing LBT was to reduce the DFW rate 10 percentage points, i.e. from 57% in spring 2013 to 47% in spring 2014. Results are discussed in Chapter 4.

3.7 Quantitative Data Analysis

SPSS was used as the statistical analysis tool for this study. The instructor provided de-identified data for cumulative GPA (CGPA), test grades, final exam grades (FEX), and final course grades for students enrolled in the spring 2012, 2013, and 2014 offerings of Thermo. The purpose of the preceding analyses were to answer the following research questions:

1. Is there a difference in the average final exam score for students enrolled in Thermo in spring 2012, spring 2013 and spring 2014?
2. Is there a difference in the course DFW rates for students enrolled in Thermo in spring 2012, spring 2013, and spring 2014?
3. How does student academic preparation influence their performance in Thermo as measured by final exam scores?
4. How does the LBT pedagogy enhance student learning and application of Thermo concepts?

5. What are students' perceptions of LBT pedagogy compared to traditional "chalk-and-talk" pedagogy?

3.8.1 Statistical Assumptions

Prior to running any statistical analyses, the viability of several assumptions were first evaluated:

1. Independence of observations
2. Homogeneity of variance (homoscedasticity)
3. Normality
4. Linearity

The raw data was entered into SPSS and organized by semester. For all tests conducted, a significance level of $\alpha = .05$ was used. The data was then screened and inspected for homoscedasticity, normality, linearity, outliers, and any missing data. This was achieved by running descriptive statistics in SPSS and examining the output.

Independence of observations was a viable assumption due to the fact that students from spring 2012 and 2013 offerings of Thermo graduated and did not interact with the spring 2014 Thermo students. The t and F statistics are robust to slight departures from normality particularly if the ratio of the largest/smallest sample sizedoes not exceed 1.5(Tabachnick & Fidell, 2001). Homoscedasticity was evaluated using Levene's F test for equality of variance. Normality was validated through the analysis of skewness and kurtosis to ensure results of each test statistic were within an acceptable range of ± 3.29 (Tabachnick & Fidell, 2001). Scatter plots of final exam scores and CGPA for all three semester were generated to validate the assumption of linearity. Qplots in linear regression models were also generated to test if the data was normally distributed. Assumptions were tenable based on the analyses conducted.

3.8.2 ANOVA Analysis

An analysis of variance (ANOVA) was conducted to determine if there was a statistical difference in the average final exam score for students enrolled in Thermo in spring 2012, spring 2013 and spring 2014. Average final exam score was the dependent variable, while the semester grouping was the independent variable.

3.8.3 Chi-square Analysis

Chi-square tests were conducted to evaluate differences in DFW rates among the three semesters. Final course grades were transformed as a dichotomous categorical variable. Letter grades of A through C were coded as “1” in SPSS. Grades of a D, F, or W were coded as a “0” in SPSS.

3.8.4 Hierarchical Linear Regression Analysis

As a means of answering the third research question, a hierarchal linear regression test was conducted to predict student performance on the final exam. Predictors including CGPA (entered first) and semester groupings (entered second) were tested.

CGPA was entered into the model first to control for its effect in determining if the semester grouping was significant in predicting final exam score. CGPA’s for all three semesters were converted to a categorical variable in SPSS using the following ranges:

(1) 1.500 – 1.999
(2) 2.000 – 2.499
(3) 2.500 – 2.999
(4) 3.000 – 3.499
(5) 3.500 – 4.000

CGPA values lower than 1.500 were not considered since it was the minimum CGPA in the sample. Semester (spring 2012, 2013, and 2014) was entered into the model as a predictor in the second step.

3.8.5 Binomial Logistic Regression Analysis

A binomial logistic regression was then conducted to determine how CGPA and semester predicted the dichotomous outcome of pass/fail rate. Logistic regression is much more flexible in that assumptions required in previous statistical tests do not need to be met, i.e. normal distribution, linearity, independence, and homoscedasticity (Tabachnick & Fidell, 2001).

3.8.6 Qualitative Measures of Students' Perceptions

Seven LBT modules were created and administered to the students during class. The modules were structured to challenge the students' problem solving process, conceptual understanding of Thermodynamic concepts, and problem-solving proficiency. Participation for each module was primarily group-based, although two modules were designed as individual modules rather than group modules. Each module identified specific learning outcomes and measures of performance associated with that week's lecture material. The researcher observed student behaviors such as attitude, engagement, quality of work, and performance during each LBT activity. Common mistakes, or learning gaps, were identified and summarized, then shared with the class via an emailed synopsis. Similarly, students were also observed during SI sessions.

In order to determine if LBT enhanced student learning and application of Thermo concepts, student feedback was gathered from two reflective writing assignments (RWA). Each RWA was assigned the day after a semester test was administered, as well as embedded into homework assignments. Each RWA was designed to promote metacognition as well as solicit feedback on course style, structure, homework/study strategies, and overall likes/dislikes of the class. The excerpt below comes from the first RWA which was administered the day after the first test, approximately five weeks into the start of the 16 week semester. The remainder of the RWAs' can be found in Appendix C.

Reflective Writing Assignment #1:

> *"This semester the small class size has allowed us to do some in-class activities that are not possible in large lecture sections. Briefly describe what you like and don't like about the activities. Explain why or how the activities have/have not been helpful in your learning. You will be graded on your ability to provide relevant and constructive feedback and not your opinions of the activities themselves. Submit this portion of the assignment as a Word document to Moodle. It will be graded as 20% of the overall homework assignment and not as a separate submission."*

In order to answer the fifth research question, an anonymous end-of-semester survey was administered to students to measure their perceptions and attitudes about the effectiveness of LBT versus traditional lecture. The survey included free response, open-ended questions and scaled items (Appendix D). As shown in Table 1, the first survey item asked the students to rate their level of agreement to nine items thought to contribute to their learning in this course using a five point Likert scale (5 = Strongly Agree and 1 = Strongly Disagree).

Table 1: Likert Scale survey items and variable names

The following contributed to my learning in this course:	
Individual problem solving	IPS
Group problem solving	GPS
Student presentations of concepts	Presentation
Reflective writing assignments	RWA
Compared to traditional lecture, the teaching style of this course better prepared me to:	
Understand difficult concepts	Understand
Apply concepts to a variety of problems	Apply
Analyze a variety of problems using different teaching techniques	Analyze
Overall, this course helped me improve my:	
Communication skills	Comm
Teamwork skills	Teamwork

In order to protect the identity of participating students, a graduate student unaffiliated with the course administered the end-of-semester survey while the student researcher and instructor were absent. The surveys were kept in a sealed envelope by a college of Engineering faculty member and were opened after final course grades were posted. A discussion of the results obtained through this research will be discussed in Chapter 4.

CHAPTER 4: RESULTS

The purpose of this study was to compare student performance in Thermodynamics over spring 2012, 2013 and 2014 course offerings. With Thermo having the highest DFW rate of all courses offered in the MET curriculum there was a need to understand why, and how the rate could be reduced. Delivery style of lecture content, students' incoming cumulative GPA (CGPA), pass/fail rates, performance on semester tests and final exams, as well as student perceptions when exposed to a non-conventional teaching style of LBT were analyzed. Implementation of the LBT pedagogy was deemed a success if the DFW rate for the spring 2014 semester was reduced by at least 10 percentage points from the 2014 or 2013 semesters.

4.1 Descriptive Statistics Results

Descriptive statistics by semester are provided in Table 2. The spring 2014 offering of Thermo had the smallest sample size of 23 students compared to 39 and 42 students in the spring 2012 and 2013 offerings, respectively. The average final exam (FEX) score for spring 2014 was the highest (71) compared to average scores of 65 and 60 for spring 2012 and 2013, respectively.

Table 2: SPSS output for descriptive statistics for tests and FEX scores

Descriptive Statistics

SEMESTER		N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
		Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
SP2012	SEMESTER	39	12	12	12.00	.000	.	.	.	.
	TEST1	39	20	99	64.23	20.327	-.140	.378	-.748	.741
	TEST2	39	19	100	62.10	21.082	-.375	.378	-.570	.741
	TEST3	39	9	100	75.36	21.416	-1.158	.378	1.286	.741
	FEX	39	24	92	65.41	15.415	-.754	.378	.642	.741
	Valid N (listwise)	39								
SP2013	SEMESTER	42	13	13	13.00	.000	.	.	.	.
	TEST1	42	8	100	64.12	25.457	-.239	.365	-.873	.717
	TEST2	42	10	100	61.26	26.386	-.075	.365	-1.247	.717
	TEST3	41	31	97	79.85	15.626	-1.543	.369	2.289	.724
	FEX	41	14	89	60.29	17.419	-.436	.369	-.289	.724
	Valid N (listwise)	41								
SP2014	SEMESTER	23	14	14	14.00	.000	.	.	.	.
	TEST1	23	41	97	68.61	17.755	.053	.481	-1.374	.935
	TEST2	23	48	100	75.48	14.641	-.121	.481	-.775	.935
	TEST3	23	47	97	85.17	11.896	-1.872	.481	3.764	.935
	FEX	23	49	88	71.00	10.059	-.343	.481	-.291	.935
	Valid N (listwise)	23								

Source: SPSS

Test three averages were found to be highest of the three semester tests amongst all three semesters. Although the kurtosis values for test three were observed to be highest for both the 2013 and 2014 groups, they still fell within the acceptable range of ± 3.29 (Tabachnick & Fidell, 2001). The largest/smallest sample size was 1.8 which exceeded the recommended ratio of 1.5 thus possibly affecting statistical power.

Table 3 displays descriptive statistics for cumulative GPA (CGPA). The data suggests that students enrolled in the spring 2014 offering of Thermo were better prepared (CGPA = 2.84) compared to CGPA values of 2.72 and 2.70 in spring 2012 and 2013, respectively.

Table 3: Descriptive statistics for CGPA by semester

Descriptive Statistics

SEMESTER		N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
		Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
SP2012	SEMESTER	39	12	12	12.00	.000	.	.	.	.
	CGPA	39	1.913	4.000	2.723	.534	.837	.378	.115	.741
	Valid N (listwise)	39								
SP2013	SEMESTER	42	13	13	13.00	.000	.	.	.	.
	CGPA	42	1.826	4.000	2.698	.549	.529	.365	-.521	.717
	Valid N (listwise)	42								
SP2014	SEMESTER	23	14	14	14.00	.000	.	.	.	.
	CGPA	23	1.938	3.857	2.844	.570	.284	.481	-1.087	.935
	Valid N (listwise)	23								

Source: SPSS

4.2 ANOVA Results

To determine if there was a statistical difference in average final exam (FEX) score between the three semesters, an ANOVA was conducted. FEX scores were entered as the dependent variable with semester as the independent variable. Before running the ANOVA, the Levene's test was first analyzed, the results of which are listed in Table 4.

Table 4: Levene's test results

Levene's Test of Equality of Error Variances[a]

Dependent Variable: FEX

F	df1	df2	Sig.
2.514	2	100	.086

Source: SPSS

Since $\alpha > .05$, equal variances exist amongst the three semesters, thus satisfying the assumption of homoscedasticity. A significant difference in average final exam scores between the semesters was also present at F (2,101) = 3.455, p = .035 and can be seen below in Table 5.

Table 5: ANOVA results

FEX

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3431.466	2	1715.733	3.455	.035
Within Groups	50151.448	101	496.549		
Total	53582.913	103			

Source: SPSS

Post hoc analyses were used to determine which semesters differed specifically. A Bonferroni post-hoc test was generated to allow for multiple comparisons between the semesters. Table 6 displays the results of the post-hoc test.

Table 6: Bonferroni post-hoc results

Multiple Comparisons

Dependent Variable: FEX

Bonferroni

(I) SEMESTER	(J) SEMESTER	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
SP2012	SP2013	5.12	3.421	.413	-3.21	13.45
	SP2014	-5.59	4.021	.503	-15.38	4.20
SP2013	SP2012	-5.12	3.421	.413	-13.45	3.21
	SP2014	-10.71*	3.984	.025	-20.41	-1.01
SP2014	SP2012	5.59	4.021	.503	-4.20	15.38
	SP2013	10.71*	3.984	.025	1.01	20.41

Based on observed means.

The error term is Mean Square(Error) = 233.919.

*. The mean difference is significant at the 0.05 level.

A statistically significant difference (p = .025) was observed for final exam averages between the spring 2014 and 2013 groups (71.00 versus 60.29). However, there was not a difference between the spring 2012 and 2013 (p = .413) groups, or the spring 2012 and 2014 (p = .503) groups.

4.3 Chi-Square Results

Table 7 below shows the final course grades for all three semesters analyzed with DFW rates provided in Table 8. The DFW rate was highest in spring 2013 (57%), i.e. the semester prior to implementing LBT.

Table 7: Final course grades

Count

		FINAL GRADE						Total
		A	B	C	D	F	W	
SEMESTER	SP12	3	10	8	12	6	5	44
	SP13	6	5	12	8	11	14	56
	SP14	0	10	7	5	1	4	27
Total		9	25	27	25	18	23	127

Source: SPSS

Table 8: DFW rates per semester

		DFW RATES				
		N	D	F	W	% DFW
SEMESTER	SP12	44	12	6	5	52.3%
	SP13	56	8	11	14	57.0%
	SP14	27	5	1	4	38.5%

Source: SPSS

The DFW rates for spring 2012 and 2013 were comparable. However, the DFW rate in spring 2014 (39%) dropped 19 percentage points compared to spring 2013 which exceeded the target of 10 percentage points. In order to determine if a statistical difference in DFW rates existed between the three semesters, a Chi-square test was conducted, results can be seen below in Table 9.

Table 9: Chi-square test results

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	19.209[a]	10	.038
Likelihood Ratio	21.680	10	.017
N of Valid Cases	127		

a. 5 cells (27.8%) have expected count less than 5. The minimum expected count is 1.91.

Source: SPSS

A significance level less than .05 (p = .038) was observed indicating a statistically significant difference in DFW rates between the three semesters.

4.4 Hierarchical Linear Regression Results

A hierarchal linear regression was conducted to predict student's performance on the final exam (entered as a dependent variable). Predictors including CGPA (entered first as a covariate) and semester as the grouping variable were analyzed. This allowed for the researcher to control for the effects of CGPA in predicting FEX scores between the semesters.

It was observed that both CGPA and semester grouping were significant predictors of FEX. As shown in Table 10, CGPA was a significant covariate in the first step of the model: F (1, 59) = 4.671, p = .035.

Table 10: ANOVA results of hierarchical linear regression test

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1350.222	1	1350.222	4.671	.035[b]
	Residual	17056.565	59	289.094		
	Total	18406.787	60			
2	Regression	2853.972	2	1426.986	5.322	.008[c]
	Residual	15552.815	58	268.152		
	Total	18406.787	60			

a. Dependent Variable: FEX

b. Predictors: (Constant), CGPA

c. Predictors: (Constant), CGPA, SEMESTER

The full model in which both CGPA and semester were incorporated was also significant: F (2, 58) = 5.322, p = .008. Each of the independent variables were then tested to determine the individual contribution to student performance on FEX scores. These results can be seen in Table 12 below.

Table 12: Standardized coefficients

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	Correlations Zero-order	Correlations Partial	Correlations Part
1	(Constant)	50.352	6.781		7.426	.000			
	CGPA	4.503	2.084	.271	2.161	.035	.271	.271	.271
2	(Constant)	47.667	6.628		7.192	.000			
	CGPA	4.161	2.012	.250	2.068	.043	.271	.262	.250
	SEMESTER	10.366	4.378	.287	2.368	.021	.305	.297	.286

a. Dependent Variable: FEX

Source: SPSS

Both CGPA and semester variables were found to be significant contributors to student performance on FEX scores ($p < .05$). The best predictor of student performance was the semester variable ($\beta = .287$) followed by CGPA ($\beta = .271$).

In the first step of the model, analysis of the adjusted R^2 value indicates that less than 6% of the variability in students' performance on the final exam is attributable to CGPA as seen in Table 11. The full model, i.e. the one that incorporates both the covariate (CGPA) and semester, was also significant and accounted for almost 13% of the variance in students' final exam grade based on adjusted R^2. Adding the second predictor, i.e. semester, improved the R^2 value by 6.8 percentage points.

Table 11: Regression model results

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.271[a]	.073	.058	17.003
2	.394[b]	.155	.126	16.375

a. Predictors: (Constant), CGPA

b. Predictors: (Constant), CGPA, SEMESTER

4.5 Binomial Logistic Regressions Results

A binomial logistic regression was conducted to determine how the categorical independent variables, CGPA and semester, predicted the outcome of the dichotomous dependent variable, pass/fail. The model correctly predicted whether students passed (ABC) or failed (DFW) 65.6% of the time, as evidenced in Table 13, which exceeds the generally accepted cut-off of 50%.

Table 13: Bivariate logistic regression classification with CGPA predictor

Classification Table[a,b]

	Observed		Predicted		
			FNL GR		Percentage Correct
			0	1	
Step 0	FNL GR	0	0	21	.0
		1	0	40	100.0
	Overall Percentage				65.6

a. Constant is included in the model.

b. The cut value is .500

When controlling for CGPA as a covariate to determine if semester groupings predicted whether student's passed, it was noticed that the overall success rate of the classification increased to 77.0% as evidenced in Table 14 below.

Table 14: Binomial logistic regression with CGPA and semester predictors

Classification Table[a]

	Observed		Predicted		
			FNL GR		Percentage Correct
			0	1	
Step 1	FNL GR	0	11	10	52.4
		1	4	36	90.0
	Overall Percentage				77.0

a. The cut value is .500

CPGA was a significant predictor (*p* = .005) while semester grouping was not a significant predictor in pass/fail results as evidenced by Table 15.

Table 15: Significance of predictors in binomial logistic regression analysis

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	CGPA	.996	.359	7.714	1	.005	2.708	1.341	5.470
	SEMESTER(1)	.904	.655	1.904	1	.168	2.470	.684	8.921
	Constant	-2.537	1.062	5.707	1	.017	.079		

a. Variable(s) entered on step 1: CGPA, SEMESTER.

CGPA was a significant predictor of whether a student will pass or fail Thermo. The Odds Ratio (β = 2.708) indicates that for every 0.5 incremental increase in CGPA, students are 2.7 times more likely to pass Thermo. The results also indicate that semester is not a significant predictor of whether a student will pass or fail ($p > .05$).

4.6.1 RWA #1 Results

Throughout the spring 2014 semester, two reflective writing assignments (RWA) were administered to the students. These assignments were designed to obtain feedback on the benefits of LBT student learning and application of Thermo concepts. In the first RWA, students were asked to describe what they liked/disliked about the LBT activities implemented throughout the semester. They were also asked to explain why and how the LBT activities have or have not been beneficial in their learning of Thermodynamic concepts. All RWA's, complete with a synopsis of each can be found in Appendix D.

The majority of students reported that working in groups increased their comprehension with the difficult topics. It was also mentioned that the LBT activities allowed students to become actively engaged and have the ability to interact with course content versus strictly copying notes. The activities helped students to effectively communicate and assist each other with the problem solving processes and procedures which in turn helped build confidence by allowing them to ask questions in class.

Not all feedback was positive, however. Students did report that the main downside to the LBT activities was the lack of time to complete them. They also found it difficult to get started with the assigned activity without relying on help/guidance from the instructor. Students requested that a hardcopy of the activity be distributed rather than displaying the activity on the overhead projector. Students also reported that it was hard to apply concepts learned in that day's lecture to the LBT activities without the instructor first completing a worked example in lecture. Feedback was also collected on students "riding the coat tails" of other group members and not fully participating in the activity.

Based on the student feedback on the RWA's, changes were made to the LBT activities and lecture. Students were provided a physical copy of the LBT activity versus only displaying the activity on the overhead projector. They were encouraged to use technology such as cameras, tablets or smart phones to capture their group work on the boards. Solutions to each activity were also posted for reference.

4.6.2 RWA #2 Results

After students were given the opportunity to re-work their solutions for test 1, the second RWA was assigned. This RWA gathered feedback of how the LBT activities were beneficial to their success on the first exam. Students were asked to provide feedback on study strategies used in preparations for test 1, what resources were beneficial to their success on test 1, as well as what problem-solving strategies from homework and LBT activities were useful on test 1. As with the first RWA, feedback was both positive and negative amongst the students.

The majority of students did report that the LBT activities helped solidify a sound problem solving process when completing test 1. Students were able to apply the same problem solving strategies from the LBT activities and weekly homework to the problems on test 1. Students found that reworking homework and example problems proved beneficial in their success of test 1. Surprisingly, students reported an average study time of approximately four to six hours in preparing for test 1, while five students reported they did not study at all.

Typical of past semesters, students reported that the time to complete the test was insufficient. Students are allotted 75 minutes to complete the 3-4 problems on each test. Three students also reported that the LBT activities were not beneficial to their problem solving process on the first test. Some students struggled with deciphering the given information in the problem statements in relation to what they were asked to solve. Students also admitted to not knowing where to begin the problem-solving process on the test.

As with the first RWA, feedback was used to modify delivery style and LBT activities. It was recommended that LBT activities and future homework problems focus more on actual problem solving processes rather than arriving at the final answer. Students also recommended the use of videos relevant to course material as a means of better understanding Thermo concepts. Timing completion of LBT activities was also recommended to simulate the time required to complete a typical test problem. With the exception of three students, the majority of the class responded that the LBT activities were extremely beneficial relative to passing the first test and would not recommend changing the structure of the course.

4.7. Survey Results

Descriptive statistics of the first survey item are provided below in Table 16. Overall, individual problem solving (91%) was found to be most beneficial to student learning, while 77% of students reported that group based problem solving assignments contributed to their overall learning in this course. It is interesting to note the only 27% of students found the RWA's to be beneficial. When asked to compare the LBT teaching style of this course to traditional courses, approximately 83% of students reported that the LBT teaching style helped in understanding, applying and analyzing concepts and techniques compared to traditional teaching practices.

Table 16: Descriptive statistics for survey variables

	N	% ≥ "Agree"	Mean	Min	Max	SD	Skew	Kurtosis
IPS	22	90.9	4.36	2	5	0.79	-1.42	2.50
GPS	22	77.3	4.09	2	5	0.87	-0.67	-0.10
Presentation	21	50.0	3.43	2	5	0.75	-0.13	-0.09
RWA	22	27.3	3.18	2	4	0.59	-0.03	0.01
Understand	22	86.4	4.23	2	5	0.81	-1.05	1.23
Apply	22	95.5	4.41	3	5	0.59	-0.35	-0.63
Analyze	22	83.4	4.27	3	5	0.70	-0.44	-0.76
Comm	21	52.4	3.67	2	5	0.86	0.22	-0.72
Teamwork	21	54.6	3.81	2	5	0.98	-0.29	-0.88

When asked what students liked *best* about the course structure, 82% reported that the in-class LBT activities were very helpful in understanding difficult concepts. One student reported that "*Student-led examples, as opposed to instructor guided examples, better facilitated learning of concepts*". A second student stated "*the in class activities* *helped to kick off the thought process for new topics covered in lecture. This led to an easier experience with homework assignments."*

The next survey item asked students to address what they liked *least* about the course structure. 86 % of students reported that the tests were too long and complex, and that more time was required to complete the tests. This is consistent with student feedback from past semesters. It is also interesting to report that one student claimed that they did not like the in-class activities. Student feedback was also similar when asked what they would change about the structure of the course. Two students reported they would not change anything.

The last two survey questions asked if the students preferred the LBT teaching/learning style compared to traditional lecture, and if the students would recommend this approach to other students. 95% of students reported that they preferred the LBT approach compared to traditional teaching styles. All students (100%) surveyed said they would recommend the LBT approach to other students.

CHAPTER 5: DISCUSSION

With Thermodynamics having the highest DFW rate of all classes within the MET curriculum, there was a need to understand why and what could be done to increase student performance and reduce the DFW rate. To increase student performance, the LBT pedagogy was implemented within the spring 2014 offering of Thermo. It was hypothesized that the alternative teaching style of LBT would enhance student performance compared to conventional "chalk-and-talk" paradigms consistent with past offerings of Thermo. Final exam scores and DFW rates were the omnibus tests for this research. Qualitative feedback was also examined to determine students' perceptions and attitude, as well as their understanding and application of Thermo concepts when exposed to LBT.

The objectives of this research were to (1) enhance student performance as measured by average final exam scores of 70 or higher, and (2) reduce the spring 2014 DFW rate by at least 10 percentage points from spring 2013 by increasing students' knowledge acquisition, comprehension, retention, and transfer of Thermo concepts and application through LBT-based instructional and SI methods.

5.1 RQ1: Is There a Difference in Average Final Exam (FEX) Scores?

The semester in which the intervention was conducted (spring 2014) experienced the highest FEX average amongst all three semesters. Results indicate a significant difference in average FEX scores between the spring 2014 and 2013 semesters. It was also determined that student academic preparation as measured by CGPA, and the semester in which they took Thermo were predictors of student performance based on FEX averages.

5.2 RQ2: Is There a Difference in Course DFW Rates?

DFW rates were also found to be statistically significant between the three semesters. The DFW rate for the spring 2014 semester was reduced by 19 percentage points (38.5%) compared to the DFW rate of spring 2013 (57.0%) and by 13.8 percentage points compared to spring 2014 (52.3%).The implementation of LBT was deemed a success due to the fact that DFW rates were reduced by 19 percentage points for the 2014 offering of Thermo compared to spring 2013. However, based on this sample of students, results of the logistic regression indicate that only CGPA was a significant predictor of whether students passed or failed Thermo; semester was not a significant predictor. The latter may be attributable to unbalanced semester sample sizes.

Reducing the DFW rate ensures student advancement within the MET curriculum and timely graduation. The fact that students needed to pass Fluid Dynamics with a C or better the semester prior to the intervention being implemented could have affected DFW rates. The fact that LBT activities actively engaged students with course content could also contribute to the difference in DFW rates. These results are similar to studies in which active learning pedagogies were also implemented. Pascarella and Terenzini (1991) reinforce the importance of active learning on the impact college has on students, by stating “Simply put, the greater the student’s involvement or engagement in academic work, the greater his or her level of knowledge acquisition and general cognitive development.”

5.3 RQ3: How Does Student Academic Preparation Influence Performance in Thermo?

A hierarchal linear regression was conducted to predict student performance on the final exam. Student CGPA was used as a proxy to measure student preparation due to the rigor and complexity of the course content in the MET curriculum courses leading up to Thermo. Based on the results, CGPA was found to be a significant predictor of both performance on the final exam and whether a student passed or failed Thermo.

The research indicates that students enrolled in the spring 2014 offering of Thermo had the highest average CGPA (2.84), thus better prepared academically, compared to an average CGPA of 2.72 and 2.70 for the spring 2012 and 2013 offerings, respectively. Not surprisingly, results indicate that students who are better academically prepared (higher CGPA) are more successful in Thermo. When semester was added as a predictor into the model there was an improvement of 6.8 percentage points in variance explained (R^2)in students' performance on the final exam.

Student performance can also be influenced by a number of external factors like work, extracurricular activities, and other class obligations. It is not uncommon for students to work while going to school, thus posing challenges in time management with a rigorous course such as Thermo. Student interest in course content can also affect student performance.

5.4 RQ4: How Does LBT Enhance Student Learning and Application?

Student feedback was gathered from two RWA's throughout the spring 2014 semester to determine if LBT enhanced student learning and application. In general, each RWA was designed to promote metacognition as well as solicit feedback regarding course style, structure, homework/study strategies, and overall likes/dislikes of the class structure. One student stated that the LBT structure "*Helps students' learn by hearing other students input and explaining concepts in a different way from the instructor"* when presenting their solutions of LBT activities to their peers. Students also reported that LBT was "*a good way to learn course material, get involved and meet new people"*. This finding is consistent with studies conducted by Ohland and Cadberry that reported that social interaction between the teacher and the learner was found to be beneficial when the LBT pedagogy was implemented in group based environments.

Students also reported that the problem solving skills used on the LBT activities were incorporated on semester tests to solidify a sound problem solving process. Overall feedback on RWA's determined that LBT did in fact enhance student learning and application of Thermo concepts throughout the semester. Research has shown that by increasing active engagement of students within a classroom environment, as the case with the LBT pedagogy, the more apt they are to retain and apply the information delivered. The ability to apply skills from the LBT activities to semester tests coincides with Gotler's research on pedagogies of engagement which found that learning improves with increased involvement in the educational process".

5.5 RQ5: What are Student Perceptions of LBT Pedagogy Compared to Traditional Pedagogy?

An end-of-course survey was administered to students to measure their perceptions and attitudes about the effectiveness of LBT versus traditional lecture. When asked what contributed most to student learning in Thermo, 90% found individual problem solving skills to be most beneficial and 95% reported that the teaching style of LBT enhanced their application of Thermo concepts to a variety of problems. More than half the students believed that LBT improved their communication and teamwork skills. The majority of students also felt that LBT activities helped them understand difficult Thermo concepts.

However, there were two observations of negative feedback on the end of course survey. One student reported that the demanding workload was very strenuous and hard to balance with a full-time school schedule. Another student reported a dislike for the LBT activities and felt as if the activities did not reinforce Thermo concepts.

Understanding concepts is essential to student success due to the fact that students must first master the remembering/understanding levels of the cognitive learning domain prior to being able to perform at the analyzing/evaluating levels in which Thermo students are expected to perform.

5.6 Limitations

As with any research, there were limitations to this study. External factors such as work load, family obligations, and other course responsibilities could impact performance in Thermo. Unbalanced sample size between the three groups also posed a threat to validity.

Not having enough time to complete LBT activities also posed a limitation to the study. Students were expected to complete LBT activities in 15-20 minutes. The majority of students felt that this was not enough time to complete the assigned tasks. Failure to display proper knowledge transfer from lecture and homework assignments to test problems could relate to high DFW rates.

CHAPTER 6: CONCLUSIONS

An active learning environment, typical of LBT, may be new for many students. With traditional "chalk-and-talk" paradigms often being the preferred method of delivery, student's struggle adapting when exposed to non-conventional teaching styles. Collaborative learning also brings out social effects in students when asked to work in groups and/or presenting to the class. The LBT pedagogy also required students to spend more time outside of class learning and applying Thermo concepts compared to traditional learning styles.

Active learning pedagogies require more time in lesson planning compared to traditional lecture. The time required to administer LBT activities within the classroom takes away from traditional lecture time allowing for less content to be covered by the instructor. This limitation could affect the pace in which the course is conventionally taught. While traditional lecture is more efficient in increasing the amount of material delivered to the students, it also imposes a limit as to what the students actually learn due to the limited active engagement students have with course material.

It is recommended that LBT be implemented in a group-based learning environment for best results. LBT should not be used in fast-paced or accelerated courses due to the time demands on both the student and the instructor. Implementing LBT in other "high risk" courses could prove beneficial in increasing students' knowledge acquisition, comprehension, retention, and transfer of course concepts.

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APPENDIX A: STUDENT OBSERVATION TEMPLATE

ETME 3143

Student Observations

Date	Student Name	Attendance (SI/Lecture)	3 = Exceeds Expectations 2 = Meets Expectations 1 = Does not Meet Expectations				Questions Asked/ Comments Made	Notes
			Engagement/ Productivity	Quality of Work	Attitude/ Interest	Performance		

APPENDIX B: PARTICIPATION ANNOUNCEMENT

ANNOUNCEMENT

In addition to being your grader and SI leader, I am also conducting a research study in partial fulfillment of the requirements for my master's degree. I am passionate about Thermo but I am even more passionate about finding ways to help you be more successful in this very difficult course.

The purpose of my study is to increase the overall student success within Thermo and reduce the historically high DFW rate associated with this course. I am excited to be able to integrate a new teaching/learning style into lecture and SI this semester based on engineering education research and social learning theories. New activities will be introduced in class and during SI to help you learn and apply difficult concepts.

Activities will be designed to strengthen your analytical, problem solving, and communication skills, as well as increase your understanding and application of difficult thermodynamic principles and concepts. These activities will also better prepare you to successfully complete homework, quizzes and tests. You will work in teams, both in class and in SI if you choose to attend. We will utilize the white boards lining the lecture hall to do some of the group work. After each quiz and homework assignment I will email the class about common mistakes and what we call "learning gaps." Dr. Tolley will do the same for each test. My observations in lecture and SI will also provide insights into how we can help you improve your performance. I will also ask you to provide some written feedback – nothing formal or long! - to gather your input about the these activities and to ask where you're having difficulty learning Thermo. We will do this through short reflective writing homework assignments and a brief anonymous end-of-semester survey.

Your participation in SI and completion of the anonymous end-of-semester survey are voluntary, but we hope that you will actively participate in both. There is no penalty on the course final grade nor will you be treated differently if you choose not to do either.

We may want to share some of your written feedback and your anonymous survey responses in my thesis report and possibly in other publications that may be of interest to engineering educators. Therefore, I would like your permission to use both if needed. Your permission is completely voluntary. There is no penalty on the course final grade if you choose not to give permission. Your feedback will help Dr. Tolley and I refine our approach to better suit the learning style and success of the class as a whole. You will also contribute to my research and also help future Thermo students.

Now I am going to pass out the form asking for your permission to use anonymous excerpts from your written feedback and anonymous survey responses. Dr. Linn will collect the surveys and hold them until after final grades are posted so that Dr. Tolley and I will not know who has given permission and who has not. Therefore, you can be assured that you will not be treated any differently nor will your final course grade be adversely impacted if you choose not to give permission. I hope that you are willing to actively participate and I look forward to working with you this semester.

APPENDIX C: REFLECTIVE WRITING ASSIGNMENTS

ETME 3143
SP 2014
Reflective Writing Assignment #1

Assignment:
This semester the small class size has allowed us to do some in-class activities that are not possible in large lecture sections. Briefly describe what you like and don't like about the activities. Explain why or how the activities have/have not been helpful in your learning. You will be graded on your ability to provide relevant and constructive feedback and not your opinions of the activities themselves. Submit this portion of the assignment as a Word document to EES. It will be graded as 20% of the overall homework assignment and not as a separate submission.

Synopsis of Student Feedback:

The Good:

- Working in groups increases comprehension of difficult concepts
- Students are actively engaged and have the ability to interact with course material
- Prefer working examples on board as a group rather than watching the professor work the examples on the board
- Many students would like to see this style implemented in other class rooms
- A way to effectively communicate and assist each other with problem solving processes and procedures
- Requires the class to actively think on a deeper level than just copying notes
- Good way to learn material, get involved and meet new people
- Helps students' learn by hearing other students input and explaining concepts in a different way from the instructor
- Builds confidence and allows students to ask questions in class

The Bad:

- Not enough time to complete activities (main downside)
- Would prefer to see a worked example prior to working problems on the board
- Some students "ride the coat tails" of the team and do not fully participate
- Too much home work
- No physical copy of the assignment to refer back to
- Not enough worked examples
- Working with students at a higher level does not benefit those who are not at that level
- Hard to apply concepts learned during that days lecture to in class problem
- Difficult to get started with problem without any help/guidance

APPENDIX C: (Continued)

Improvements:

- Provide hard copy of in-class activity for all students
- Post in-class activity solutions to Moodle
- Provide a few “hints” or triggers to get the problem solving process flowing
- Encourage students to use devices such as cameras/tablets/phones etc. to capture their groups work from the boards
- Stress the importance of communication between team members to ensure all students are on the same page/learning level
- Students will have the option to work at boards or at desks as long as every team member is actively participating

APPENDIX C: (Continued)

ETME 3143
SP 2014
Reflective Writing Assignment #2: Synopsis

Assignment:
Now that you have re-worked your first exam, I would like your feedback on the subjects listed below. This will help me ensure that the time you are spending on activities such as homework and in-class assignments are beneficial to your success in this class. Once I have collected your feedback, I will provide the class a summary of my findings, as with the previous writing assignment.

- Which problem-solving strategies that you used to complete homework assignments and in-class activities did you find useful for test #1?
- Approximately how much time did you spend studying for test #1?
- Which resources (i.e., SI, attending office hours, etc.) did you find most helpful when studying for test #1?
- Which study strategies will you use going forward to improve your performance on future tests?

List the types of in-class activities you would like to see incorporated into the remainder of the class, given a timeframe of 15-20 minutes.

Synopsis of Student Feedback:

The Good:
- Students were able to benefit from SI sessions
- The 1st law diagram was very beneficial in completing Test 1
- Understanding of P-v and T-v diagrams was key for Test 1
- Students were able to benefit from reworking homework and example problems in the book in preparing for Test 1
- In-class activities helped the majority of students solidify a sound problem solving process.
- The same strategies used on homework (i.e. given, find, solution approach) worked best when completing Test 1
- The review sheet was very helpful when studying for Test 1
- Using different color highlighters to mark given information was helpful
- Majority of students studied for approximately 4-6 hours.

APPENDIX C: (Continued)

The Bad:

- Time was a major issue
- Not proficient enough in problem solving
- Approximately 5 students did not study for Test 1!
- Some students had a difficult time figuring out where to start
- Deciphering the given information in the problem statement and relating that to what had to be solved for was problematic
- Studying the night before the test was not enough time to prepare for Test 1
- 3 students felt as if the in-class activities were not useful in their problem-solving strategies for test 1

Improvements: future test preparation:

- Studying more
- Attending SI/office hours
- Working more example problems
- Timed completion of previous homework/book examples
- Implement homework strategies on tests (i.e. given, find, solution method)
- Reviewing worked examples from the book

Improvements: in-class activities:

- Activities that focus on problem solving processes rather than focusing on arriving at the final answer
- Activities structured around the ones similar to potential test problems
- Videos that can relate to course material covered that day
- Reviewing homework problems from previous assignments instead of doing activities related to new material
- With the exception of the few students who feel they did not benefit from the in-class activities, the rest of the class feel as if they are benefiting tremendously and would not change the current structure

APPENDIX D: END OF COURSE SURVEY

ETME 3143
THERMODYNAMICS

End-of-Course Survey
Spring 2014

The purpose of this *voluntary* and *anonymous* survey is to solicit your perspectives about the course and some of the activities implemented in class and during SI. You are encouraged to add your comments and suggestions in the open-ended questions of this survey.

Do not put your name, student ID number, or any other personal information on this survey! Your responses are anonymous and only summarized results will be reported. Results will be used to improve the learning experience for future Thermodynamic students. Thank you for your participation.

Please circle your level of agreement response to the following questions.

1) ***The following contributed to my learning in this course:***

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
The following contributed to my learning in this course:					
Individual problem solving	5	4	3	2	1
Group problem solving	5	4	3	2	1
Student presentations of concepts	5	4	3	2	1
Reflective writing assignments	5	4	3	2	1
Compared to traditional lecture, the teaching style of this course better prepared me to:					
Understand difficult concepts	5	4	3	2	1
Apply concepts to a variety of problems	5	4	3	2	1
Analyze a variety of problems using different teaching techniques	5	4	3	2	1
Overall, this course helped me improve my:					
Communication skills	5	4	3	2	1
Teamwork skills	5	4	3	2	1

Please give specific examples or details when responding to the following questions.

2) What did you like **best** about the way this course was structured (lecture, SI, in-class activities, etc.)?

APPENDIX D: (Continued)

3) What did you like **least** about the way this course was structured (lecture, SI, in-class activities, etc.)?

4) What, if anything, would you change about the structure of this course?

5) Based on your experiences this semester, what advice would you give future thermo students that would ensure their success in this class?

6) I prefer the teaching/learning approach of this course compared to traditional teaching styles.

_____ Yes _____ No

7) I would recommend the teaching/learning approach used in this course to other students

_____ Yes _____ No

Additional Comments (optional):