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Implementing Competency-Based Assessment in an Undergraduate Thermodynamics Course

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Abstract

This paper examines the implementation of competency-based learning assessment in an undergraduate thermodynamics course. Following a method presented for an undergraduate dynamics class at the 2018 ASEE Annual Conference, subject matter in this class was divided into three categories – preliminary, required, and supplementary topics. Each category included multiple sub-topics, with a total of 13 sub-topics for the whole semester. Students were quizzed on each subtopic. Students could not take quizzes on topics in the next category unless they received a score of 88% or better on all the quizzes in the current category. Student scores on specific final exam questions were compared to those of students in a course taught using traditional methods. Results show similar performance on theory questions but a marked improvement in student ability to solve calculation problems of fundamental topics when taught using CBL, and student feedback was also extremely positive. Pros and cons of this method of teaching are discussed, and several recommendations for improvement are made.

Introduction

Thermodynamics is considered a very difficult course in many undergraduate engineering programs. The concepts of "enthalpy" and "entropy" can be challenging to grasp, and most courses cover numerous topics, leading to a fast-paced course where some students fall behind. The author has taught this course numerous times in a traditional format that uses lectures combined with active learning. While small improvements in course achievement have been seen due to minor improvements (adding iClickers, adding "Gateway" quizzes), overall the failure rate in the author's class has remained fairly steady over almost 20 years at about 22% (A failure is considered to be a grade of D+ or below because at the author's institution that is the minimum grade needed to move to the next course.).

In Summer 2018, the author attended the ASEE National Conference and attended Kurt DeGoede's presentation on the implementation of competency-based assessment in an undergraduate dynamics course [1]. This method seemed ideal to help students successfully master the fundamental learning outcomes that come early in a thermodynamics class and thus was implemented in Spring 2019. This paper outlines the major benefits seen with this method but also the drawbacks. Recommendations for future improvements will also be discussed.

Background Literature

In courses using Competency-Based Learning (CBL), students advance to more complex topics only when they have mastered prerequisite learning outcomes. Thus, learning is self-paced and focusses on achievement of fundamental topics that are the backbone of later topics presented in a course. In the typical implementation of CBL, assessment focuses on students' ability to apply theoretical knowledge to solve practical problems. Although the term has been around for almost a century, it started to become more popular in the 1970's. See, for example, Spady's work [2, 3], which examines CBL for public K-12 education.

There are many publications that discuss CBL in different settings. Henri, et al. [4] presented a comprehensive review in 2017. They indicate that CBL may be beneficial for the success of a diverse student body and may also serve the needs of industry, which needs a cadre of engineers who have mastered fundamental engineering skills. Discussions of implementation of a variety of CBL-related methods in engineering programs have been published, such as [5] and [6]. Some papers focus heavily on CBL for the "soft skills" embedded within engineering programs, such as [7]. Studies analyzing a wide range of disciplines indicate that compared to traditional methods, CBL helps students attain higher achievements levels and at the same time develop stronger confidence in their abilities [8, 9].

Current Implementation

In Spring 2019 at the author's university, two sections of ME 113 Thermodynamics were taught, each starting early in the morning (8:00 and 8:40) start times. This is a 4-unit class that meets twice a week for 100 minutes per session. One section with an enrollment of 26 was taught using traditional methods, including lecture, active learning in class where students solved problems, and regularly scheduled quizzes and exams. The second with an enrollment of 39 used CBL. The sections were taught by different instructors, but both had taught this course many times in the past with good student evaluations.

Following DeGoede's method [1], subject matter in this second class was divided into three categories – preliminary, required, and supplementary topics. Each category included multiple sub-topics, with a total of 13 sub-topics for the whole semester as shown in Table 1. Each sub-topic covered certain course learning outcomes. "Preliminary Topics" included background information and skills needed for the rest of the semester. "Required Topics" included topics necessary for a basic understanding of fundamental thermodynamic processes. "Supplementary Topics" covered practical implementation.

Starting with the fourth class period, students had the opportunity to take up to two quizzes per week (one per class session). Students were quizzed on each subtopic. Students could not take quizzes on topics in the next category unless they received a score of 88% or better on all the quizzes in the current category. One quiz per subtopic was scheduled on a date published on the syllabus, typically for the last 20-30 minutes of the 100-minute class. During class periods when no quiz was scheduled, students worked on group problem-solving for the last 20-30 minutes of the class period. Students could retake a quiz instead of working on the group problem.

The remaining 70-80 minutes of class time was devoted to traditional lecture and small group or individual problem-solving. Over the course of the semester, students watched 11 videos outside of class, to leave more time in class for problem-solving. Of the 11 videos, five were recorded by the instructor and six were from YouTube.

In addition to the learning outcomes assessed by quizzes, two additional learning outcomes were discussed in the class and assessed separately – one dealing with environmental issues such as global warming and ozone depletion (assessed with a short paper and a final exam question) and one dealing with system modelling and optimization, where students modelled and optimized thermodynamic systems using the program Engineering Equation Solver.

Table 1 Thermodynamics Class Quizzes and Learning Outcomes

Quiz Topics	Related Learning Outcomes
Preliminary Topics	
1. Property Tables 2. Ideal Gas Law	• Use tabulated data and equations of state to determine the phase and properties (temperature, pressure, specific volume, internal energy, enthalpy and entropy) of a pure substance. • Discuss basic thermodynamic terms, such as enthalpy, entropy, specific and relative humidity, dew point, and adiabatic saturation and wet-bulb temperatures, in simple enough terms that someone outside the field of thermodynamics could understand what they are. (This LO relates to all three categories.)
Required Topics	
3. 1^{st} Law for Closed Systems 4. 1^{st} Law for Steady State Steady Flow Devices 5. 1^{st} Law for Uniform State, Uniform Flow Processes 6. Isentropic Processes 7. Isentropic Efficiency	• Analyze the thermodynamic performance (i.e., calculate work or heat input or output, mass flow rates, and first and second law efficiencies) of common steady-flow engineering devices such as pumps, compressors, turbines, nozzles and diffusers, expansion valves, heat exchangers, and mixing chambers using the first and second laws of thermodynamics and the conservation of mass. • Apply the first law of thermodynamics to simple unsteady-flow problems. • Explain physical aspects of the first and second law of thermodynamics, and apply them in solving real engineering problems.
Supplemental Topics	
8. Otto and Diesel Cycles 9. Brayton Cycle 10. Rankine Cycle 11. Vapor-Compression Cycle 12. Gas Mixtures 13. Air Conditioning Processes	• Analyze the performance of basic energy conversion cycles, including calculation of work, heat input or output, mass flow rates, and first law efficiencies. This involves the ability to a) Analyze the performance of a simple Otto cycle and Diesel cycles b) Analyze the performance of a simple Brayton cycle and one with regeneration. c) Analyze the performance of a simple Rankine cycle and one with reheating and regeneration. d) Analyze the performance of a simple vapor compression cycle. • Analyze the thermodynamic performance of non-reacting gas mixtures. This involves the ability to a) Calculate properties of ideal and real gas mixtures. b) Explain why condensation forms using technical terms. c) Analyze different air-conditioning and cooling processes involving air-water vapor mixtures.

Grading was as shown below:

Essay, EES problems	10%
Quizzes	65%
Final Exam	25%

The quiz grade was based on how many quizzes were passed with a score of 88% (B+) or better, as shown in Table 2.

Table 2 Quiz Grading

number of quizzes passed	13	12	11	10	9	8	7	6	5	4	3	2 or 1
grade	A plus 3 points extra credit	A	A-	B+	B	B-	C	C-	D+	D	D-	F

Results

The percentage of students who successfully completed different quizzes is shown in Figure 1. Ninety-one percent of students passed all of the preliminary and required topic quizzes, and 71% passed at least one cycle quiz.

Student scores on specific final exam questions were compared to those of students in the course taught using traditional methods. Both sections used multiple choice questions from a published Thermodynamics Concept Inventory to gauge student understanding of fundamental concepts, and the average score for the two sections was the same (71.9% for CBL and 73.5% for traditional grading). The two final exams also included one common calculation problem – second-law analysis of a steam turbine, which is covered by the final “required topic” quiz for the CBL section. Students with competency-based grading scored an average of 73% compared to 37% for traditional grading; 69% of students in the CBL section achieved a score equivalent to a C- or better on this problem vs. 14% in the traditional section.

A part of this difference may be due to the difference in the student body of the two sections – the mean GPA of students enrolled in the CBL-based method was slightly higher than the GPA of students in the traditional method (2.98 with a standard deviation of 0.48 vs. 2.74 with a standard deviation of 0.53). However, this small difference in student GPA would not account for such a large difference in student performance on the exam. The final exam for the traditional method also covered a wider range of material, which may have contributed to those students’ lower performance as well. The final exam for the CBL class only covered topics related to preliminary and required topics.

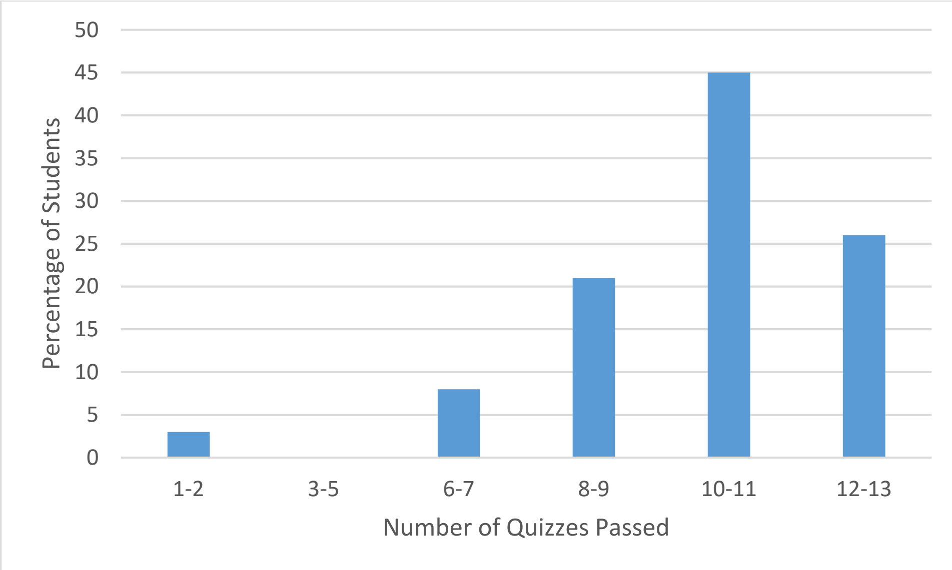

Figure 1 – Number of quizzes passed by students out of a maximum of 13.

Final course grades were also compared for two sections of the class taught by the same instructor in two different semesters, as shown in Figure 2. While the percentage of “A” grades (which includes both A’s and A-‘s) was similar, fewer students with the CBL method received failing grades of D or F.

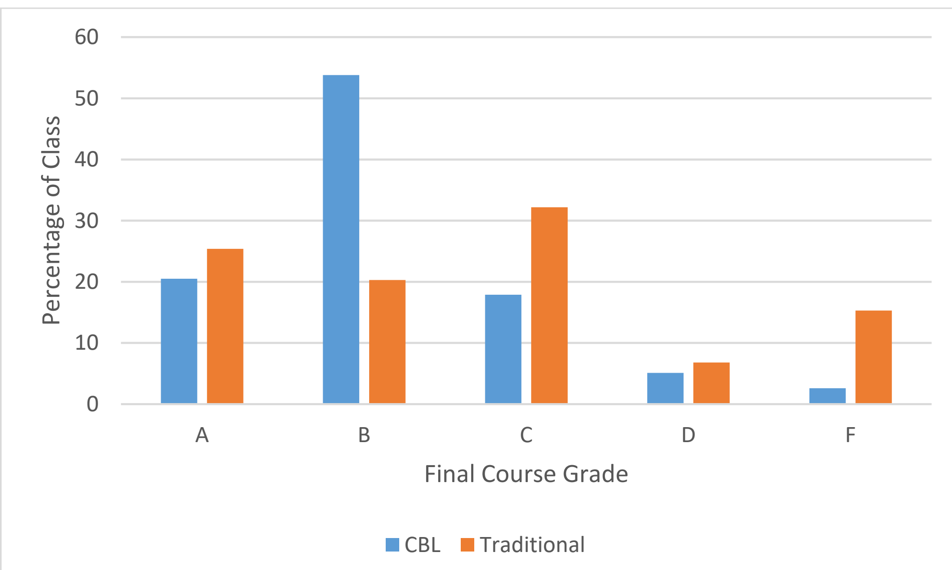

Figure 2 – Course grade distribution for ME 113 Thermodynamics using two different methods

Pros and Cons of this CBL Implementation

Pros: Thermodynamics is a course where content builds – later content cannot be mastered without a strong understanding of thermodynamics properties, phase change, and the first and second laws of thermodynamics. Because students could not move on until they mastered earlier content, we saw greater success in students' abilities to solve basic thermodynamic calculation problems compared to traditional methods. Using the traditional method, there are always students who flounder in the second half of the semester because they never mastered the fundamental content taught in the first half. The final exam results support the conclusion that students' abilities to solve fundamental calculation problems significantly improved. This method didn't appear to help the top students learn more, but they helped the weaker students achieve a higher level of achievement and understanding. Students also really liked the class structure, and the exams motivated students to attend class – despite the 8:40 am start time. Example comments from the student evaluations include the following:

"The new teaching method helps to understand each section of the course efficiently."

"The method of teach was effective as student will have a good understanding of a previous lesson before moving on."

"I really enjoyed the quiz system because it allowed for students to show that if given the chance, they will learn from their mistakes and prove that they know better."

Cons: Some students never solved any problems for higher-level topics, particularly for air conditioning processes and mixture analysis. Those students may have a difficult time when they take courses that use that content (such as SJSU's Thermal Engineering Lab class, which includes an air conditioner experiment). Additionally, the course was extremely time intensive for the instructor. Because students in a given week were taking many different quizzes, numerous quizzes had to be developed and graded. In Spring 2019, the maximum number of different quizzes written and graded in one week was 11 – a huge time commitment. While the second time around the workload will be less, since some quizzes can be re-used, this will remain an issue unless quizzes are placed online or a student assistant can be trained to take over some of this tasks.

An additional con is that the quiz structure does not lend itself well to open-ended questions. Students know the section of the textbook each quiz will cover, and thus they do not gain the important experience of deciding which method to use for a particular problem until the final exam.

Improvement Recommendations

In Spring 2020 three changed were implemented. 1) Some of the topic quizzes were combined for a maximum of 10 quizzes rather than 13. This reduced workload and also reduced the amount of class time spent taking quizzes. 2) Weekly homework assignments were added back in as 10% of the grade, to motivate students to complete them. In Spring 2019 online homework was assigned to help students prepare for quizzes but was not included in the course grade, and thus many of the weaker students skipped it. These improvements were recommended not only by the instructor but by a number of students in the class as well. 3) An open-ended design project was added for the Spring 2020 semester. Because the quizzes largely involved short calculations, a project was needed to help students integrate the learning they received on a variety of topics and apply it to problem where there was no "correct" answer.

Additionally, it could be interesting to compare student achievement using CBL to that of students in a flipped classroom with a traditional assessment timeline. While the author does have some videos that students watch outside of class to leave more class time for problem solving, the author does not have immediate plans to completely flip the course.

Conclusions

CBL clearly is not a good option for all classes. However, for a class like Thermodynamics where fundamental topics come first followed by more complex applications later in the semester, CBL can help students achieve the fundamental understanding that they need to be successful in the course. And that fundamental knowledge is important for their success as engineers upon graduation.

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