A Media-Enhanced Thermodynamics Primer

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Abstract

In order to enhance student learning in an integrated thermal-fluid-science course at Union University, a media-enhanced thermodynamics primer has been developed. To help student understanding and allow for more in-class problem solving time, the author moved to a flipped classroom approach during spring 2012 [1] and since then more than 200 screen-casts have been recorded by the author. The course content and developed screencasts have been combined as a digital (PDF) media-enhanced thermodynamics primer introduced during the spring 2019 semester. The primer provides a condensed presentation of the essential thermodynamics material supplemented with directly linked screencasts which provide example problems and added explanations. The goal of this approach is to make the learning process more student-centered. While data is limited due to small course sizes at Union University, students during spring 2019 showed improved performance on all thermodynamics exams when compared to students in previous years.

Keywords

thermodynamics, screencasts, flipped classroom, student-centered learning

Introduction

In order to enhance student learning in an integrated thermal-fluid-science course at Union University, a media-enhanced thermodynamics primer has been developed. Teaching thermodynamics in an integrated thermal-fluid-science course can be challenging for both students and faculty due to the range of topics covered and the limited number of textbooks designed specifically for such integrated courses. To improve student understanding and allow for more in-class problem solving time, the author moved to a flipped classroom approach during spring 2012[1]. Since then more than 200 screencasts have been recorded by the author and organized into twenty 30-60 minute lessons that combine a multitude of short screencasts interspersed with quizzes for immediate student feedback. These lessons are then provided to students through the course management software and students complete an online lesson prior to each class period. An example from a lesson on the "2nd Law of Thermodynamics" is shown in Figure 1.

Further, in line with recent practice in thermodynamics education (see for example, Bhattacharjee[2] or Struchtrup[3]), the course content has been re-organized such that both the 1st and the 2nd law of thermodynamics are introduced at the beginning of the course. (To the best of the author's knowledge, none of the currently existing integrated thermal-fluid-science textbooks introduce the 2nd law of thermodynamics towards the beginning of the course.) To provide

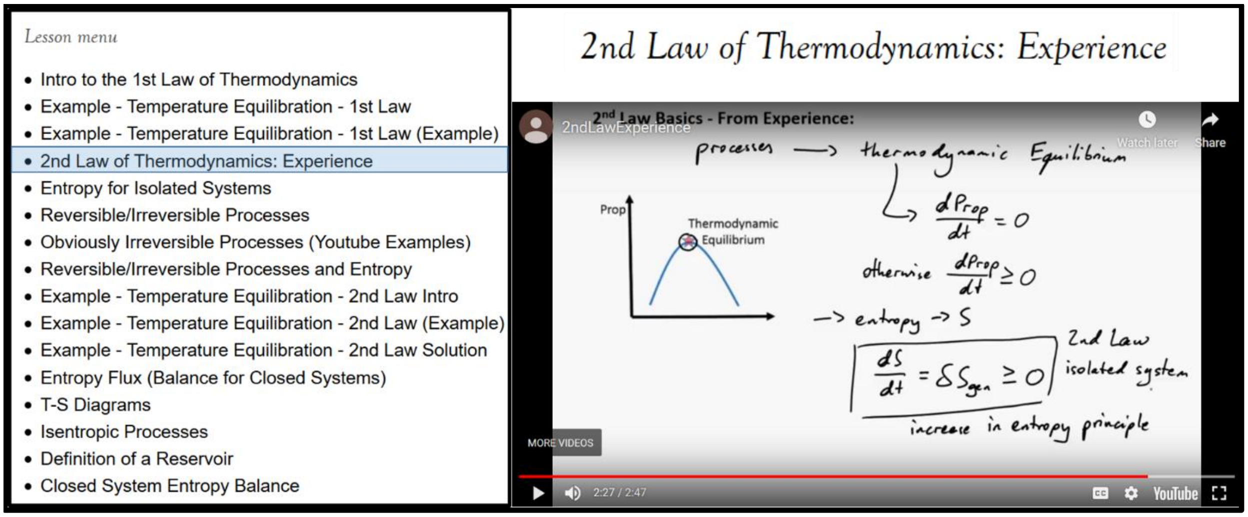

Figure 1: 2nd Law of Thermodynamics Online Lesson

students with a textbook that follows the same content coverage as the corresponding course at Union University, and to directly integrate the developed screencasts, a digital (PDF) media-enhanced thermodynamics primer is being developed by the author and was first introduced to students during the spring 2019 semester. While extensive screencasts have been developed by others and some have been organized as specific add-ons for thermodynamics textbooks (see for example Falconer et al.[4] at the University of Colorado at Boulder, who have made extensive resources available through the LearnChemE website) the current work goes one step further by tightly integrating text and screencasts. The primer provides a condensed presentation of the essential thermodynamics material supplemented with directly linked screencasts which provide example problems and added explanations. The goal of this approach is to make the learning process more student-centered, putting the student in control of their learning through a concise coverage of the material with optional opportunities to get more in-depth explanations and examples when necessary. In the following sections, the contents of the thermodynamics primer will be briefly outlined, some examples will be shown, and the impact on student learning will be briefly considered.

Thermodynamics Primer Overview

The thermodynamics primer consists of written as well as multi-media enhanced components such as screencasts and online lessons/quizzes. The goal of the written portion of the thermodynamics primer is to briefly and clearly introduce the essential components of thermodynamics. In-depth illustrations, explanations, and examples are mostly presented via the integrated screencasts. With the initial focus being students in an integrated thermal-fluid-sciences curriculum, the thermodynamics primer has been divided into the following chapters:

1. Thermodynamic Definitions and Properties
2. The 1st Law of Thermodynamics
3. The 2nd Law of Thermodynamics
4. Application of the 1st and 2nd Law to Closed Processes and Cycles

5. Application of the 1st and 2nd Law to Open Processes and Cycles

An excerpt from "Chapter 3.2: Entropy and the 2nd Law" is shown in Figure 2 on the following page. The symbols highlighted in yellow are links to screencasts recorded by the author and hosted on YouTube. The video symbol appears throughout the book, linking to the more than 200 screencasts developed for the first course in the thermal-fluid-sciences sequence at the author's university. Highlighted in red are references to the course management system lesson and quiz which are relevant to the particular textbook material. Using the PDF version of the thermodynamics primer, students thus have immediate access to in-depth explanations and example problems that supplement the written content by selecting the links, which then open the media content.

In addition to the basic coverage of thermodynamics, the primer includes brief but highlighted "Look Ahead", "Interesting Facts", and "Application Problems" sections that go beyond the essential material needed for the thermodynamics portion of the course and provide brief glimpses as to how the thermodynamics material will show up as part of either the fluid mechanics or heat transfer course content, or illustrate more advanced applications. Figure 3 shows one such example, illustrating how Bernoulli's equation is obtained from the 1st law of thermodynamics by summarizing equations previously derived in chapter 2 of the primer.

Further, throughout the primer, a conscious effort is made to relate concepts relevant to thermodynamics to concepts encountered by students in previous courses. Figure 4 shows a particular example where the concept of a path function is illustrated to students through the use of a spring – mass system as previously encountered in physics and statics courses. The goal here is to make new and sometimes complicated concepts more readily accessible to the students.

Finally, the format of this primer provides an opportunity to introduce students to concepts typically not touched upon in an introductory thermodynamics text. A specific example is the use of an "Advanced Application" problem for gasoline engines that includes the chemistry of the combustion process. It is the author's hope that providing the students with glimpses of advanced topics without the need to cover those topics in full detail will motivate the students and provide them with a glimpse of things to come in later courses in the engineering curriculum.

Effect on Student Learning

The introduction of the media-enhanced thermodynamics primer has been the author's most recent focus in order to improve student learning in the combined thermal-fluid-sciences course at Union university. Students seem to appreciate the organized and condensed nature of the thermodynamics primer and its integration with online content in the course management software. Compared to past years, students seem to be gaining a clearer understanding of the course material. The introductory thermal-fluid-sciences course is a notoriously difficult course that has required the author to provide students with re-take exam opportunities to make up for poor test performances in past years.

3.2 Entropy and the 2^{nd} Law

3.2.1 Isolated Systems[1]

From experience we know that **physical systems tend towards equilibrium** – specifically, any **isolated** physical process will eventually reach a steady-state at which the system state stops changing. Mathematically/physically we can thus attribute some "property" to our system which is constant at equilibrium and has derivatives pointing towards equilibrium elsewhere.

While it might be easiest to think of this steady-state as a "valley" – such as a ball rolling down a hill and eventually coming to rest as shown in Figure 1(a), thermodynamics has traditionally defined this property as having a 'maximum' value at the equilibrium state as shown in the Figure 1(b). If we call this property S, we can make the following statements:

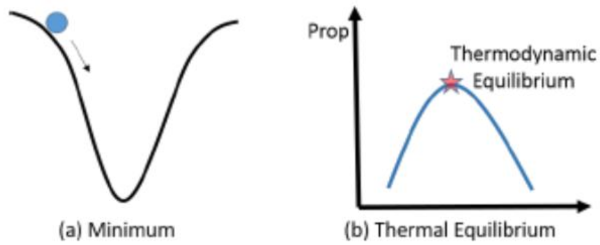

Figure 1: Thermal Equilibrium

a) At steady-state $\frac{dS}{dt} = 0$

b) When not at steady-state, $S \Rightarrow S_{max}$ and thus $\frac{dS}{dt} > 0$

The property S is referred to as **entropy** and we can define the entropy generation rate as $\dot{S}_{gen} = \frac{dS}{dt}$. We can then summarize this basic observation as the 2^{nd} **Law of Thermodynamics for Isolated Systems**:

$$\frac{dS}{dt} = \dot{S}_{gen} \geq 0 \qquad [\tfrac{W}{°K} \text{ or } \tfrac{Btu}{s*°R}] \quad (3.1)$$

$$\Delta S = S_{gen} \geq 0 \qquad [\tfrac{J}{°K} \text{ or } \tfrac{Btu}{°R}] \quad (3.2)$$

A process for which $\dot{S}_{gen} = 0$ is referred to as a **reversible** process. While such processes are impossible to achieve in the real world, they provide a thermodynamic "ideal" for the best that could possibly be achieved. Thus, the study of **reversible/irreversible processes** will be key as we continue to analyze thermodynamic systems.

At this point we can revisit our previous example to placing 2 objects at different temperatures in an isolated system by first **writing the 2^{nd} law for the system**, second by **showing when the 2^{nd} law is violated and satisfied**, and third by **showing that at thermodynamic equilibrium both objects will have the same temperature**.

[1] see MoodleRooms Quiz 7 Question 1

Figure 2: Excerpt from Chapter 3 of the Thermodynamics Primer

!!! Look Ahead – Bernoulli's Equation !!!

For steady-flow systems, the 1st Law is given as:

$$0 = \dot{Q} - \dot{W} + \dot{E}_{mass,in} - \dot{E}_{mass,out} \tag{2.25}$$

If such a system experiences no work and no heat transfer and has a single inlet/outlet, the 1st law simplifies to:

$$e_{in} = e_{out} \tag{2.26}$$

Neglecting internal energy changes, we obtain a balance of mechanical energy:

$$\frac{P_{in}}{\rho} + \frac{V_{in}^2}{2} + gz_{in} = \frac{P_{out}}{\rho} + \frac{V_{out}^2}{2} + gz_{out} = Const \tag{2.27}$$

This is a form of **Bernoulli's Equation**, which is frequently used in Fluid Dynamics

Figure 3: Obtaining Bernoulli's Equation from the 1st Law of Thermodynamics

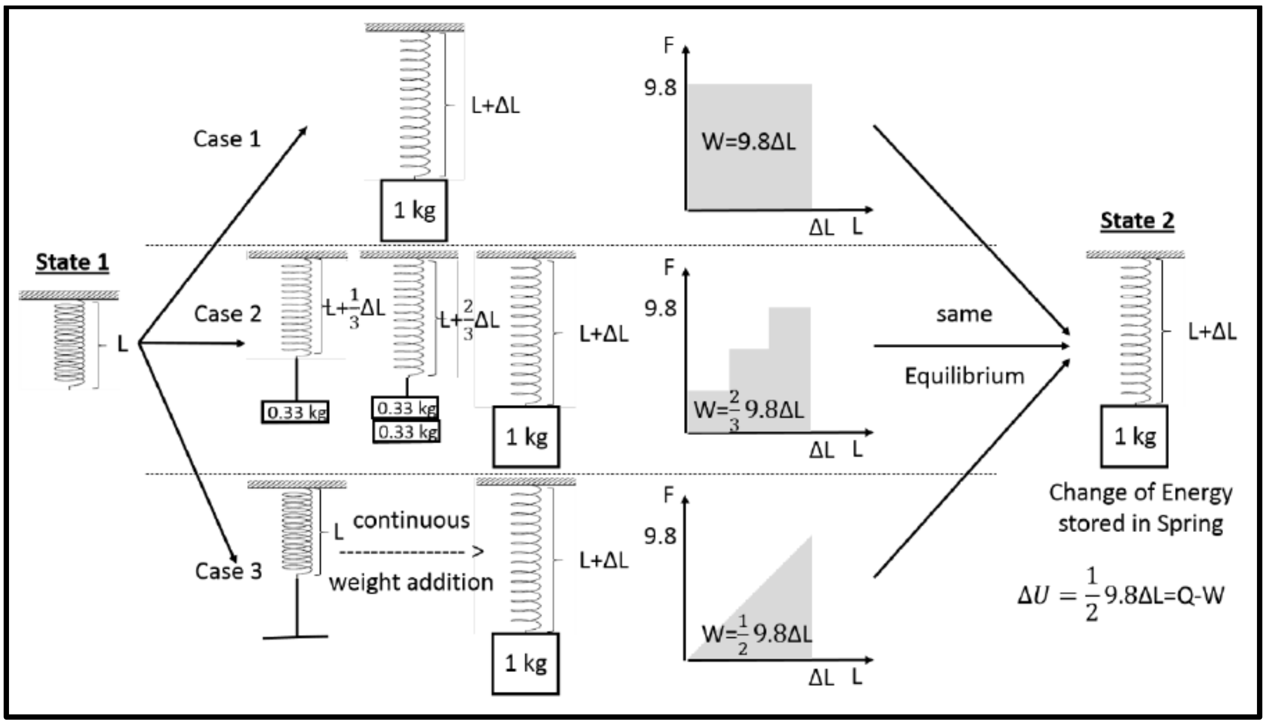

Figure 4: Excerpt from Chapter 2 – Illustration of Work as a Path Function

Following the introduction of the thermodynamics primer during spring 2019, the author can report that students' exam scores indicate improved performance on all thermodynamics exams – on average one letter grade better than during the spring 2017 and 2018 semesters as shown in Table 1, below. A more detailed statistical comparison between the individual student exam grades shows that a statistically significant improvement at the 90% confidence level can only be shown for three of the six previous exams. Further, it must be noted that the sample size – 10, 11, and 7 students, respectively – is small. Finally, while all exams had problems that tested the same material and problems with similar difficulty were selected, each exam had different problems. Thus, the small sample size, lack of control environment, and limited time-frame make it hard to quantify the benefits of the primer. However, requests from past students for access to the thermodynamics primer in order to help them study for follow-up courses and comments from those students indicating how helpful the primer has been for them as they have had to review and apply the material from our introductory thermal-fluid-sciences course to their upper level courses, further indicate a benefit of the primer for students.

Table 1: Thermodynamics Average Exam Performance

	Spring 2017	**Spring 2018**	**Spring 2019**
Thermo Exam 1	70/100*	76/100	84/100
Thermo Exam 2	64/100*	71/100*	83/100
Thermo Final	74/100	71/100	82/100

* A one-tailed t-test shows a statistically significant improvement for the Spring 2019 grades at a 90% confidence level

Future Work

Writing the thermodynamics primer as a textbook is a work-in-progress. Having completed the first edition of the primer for spring 2019 with many previously developed/recorded screencasts, it is the author's goal to re-work the screencasts to develop them specifically for the primer, further strengthening the integration of text and multi-media enhancements. In addition, while the primer includes some property tables generated from the National Institute of Standards and Technology's (NIST) extensive online property tables[5], students are currently still required to purchase another textbook with property tables for the course. It is the authors goal to find a better solution to more directly integrate property table access into the thermodynamics primer. Further, the author plans to extend the text to also cover the fluid dynamics and heat transfer topics in the thermal-fluid-sciences course at Union university. Colleagues at other institutions are encouraged to share the primer with their students and to provide feedback for improvements. The author hopes that this primer will help students everywhere gain an improved understanding as well as an increased love for thermal-fluid-sciences. Publishing yet another printed thermodynamics text (many excellent ones exist) is not the goal of this work. Instead, the media-enhanced PDF version of the text will be freely available to anyone interested.

Conclusions

The author has written a concise "media-enhanced" thermodynamics primer for students in an introductory thermodynamics or thermal-fluid-sciences course. The textbook has been typeset in LaTeX and the first edition was completed during January of 2019 and has replaced the traditional text as the primary thermodynamics textbook in the author's course. Currently the thermodynamics primer condenses the essential material in thermodynamics on 76 pages and supplements/enhances the written content by directly linking to screencasts which provide example problems and added explanations. Initial student feedback and test outcomes are encouraging and indicate improved student performance.

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