Developing an open textbook on introductory thermodynamics

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Abstract

As the cost of university textbooks continue to rise, students are increasingly hesitant to purchase required course materials. Affordability and accessibility have become undeniable barriers that have a negative impact on the academic performance of students, in particular, those from low-income families. The economic downturn during the COVID-19 pandemics further exacerbates the situation, challenging institutions to continue working on innovative approaches to affordable and equitable higher education. To address the issue of textbook affordability, many universities in the US and Canada are developing incentive programs that support faculty to develop and adopt open educational resources (OER). This paper documents the author's journey of writing and publishing an open textbook, *Introduction to Engineering Thermodynamics*. It addresses the essential elements of open authoring and shares the author's practical experience. The open textbook has been adopted by an engineering class as a supplementary text, and the survey results indicate positive feedback from students.

Introduction

Textbooks have long been a staple of college education, but their cost can pose a significant burden on students. According to the 2019 College Board research, the average annual cost for books and supplies for full-time, undergraduate students at a four-year university is approximately $1240 [1]. At the University of British Columbia (UBC), the average cost of textbooks for undergraduate students rose from $893 in 2021 to $1,253 in 2022. As a result, a staggering 70% of undergraduates reported not purchasing textbooks [2]. The high cost of textbooks can negatively impact students' access to learning materials, course selection, and academic performance [3, 4]. The COVID-19 pandemic has further exacerbated the situation, challenging institutions to continue working on innovative approaches to affordable and equitable higher education [5].

Open education resources (OER) are learning resources that are openly licensed and freely accessible for users to adapt and share. The use of OER can help address student financial barriers to quality learning materials. In addition, OER promotes shared knowledge and improved accessibility. Unlike commercial textbooks, OER can be edited and updated as needed, making them a more adaptable and flexible resource for both students and instructors. Research shows that the use of OER may lead to better student retention [6]. Although there is a wide interest in OER among engineering students and instructors, a large-scale adoption relies on the development of OER in a wide range of engineering subjects for both general and specialized courses.

Thermodynamics is a critical subject in many engineering, physics, and chemistry fields. As such, it is often introduced to junior-year undergraduate students as a one-term or two-term course. In the School of Engineering, UBC Okanagan, this course is offered to second-year undergraduate students, with an enrollment of nearly 400 students per academic year, and this number is expected to increase further in the upcoming years. While there are many commercial textbooks available on the subject, they can be costly and present a financial burden to many

students. To alleviate this burden and provide a more freely accessible alternative, I wrote an open textbook, *Introduction to Engineering Thermodynamics* [7], during the summer of 2020-2022. This paper will examine key aspects of open authoring and share practical insights. A survey was administered to the first group of engineering students who used this open textbook, and their views on open educational resources and their learning experiences will also be discussed.

Journey of open authoring

Planning

As a long-time instructor of undergraduate thermodynamics, I have gained first-hand insight into the financial challenges and textbook affordability issues that many students face. In an effort to support my students' learning, I have been distributing my course notes to them for years, which has been well received and helped many students succeed in my course. The idea of writing an open textbook on thermodynamics naturally came to mind as I explored new opportunities to further develop my course notes with the goal of reaching a wider audience of students and instructors. However, writing an open textbook is a significant undertaking that requires proper planning and commitment. The planning phase is crucial in defining the scope of the work and securing the necessary resources for the project. During this phase, I used the following questions to guide my thought process.

- Why is this open textbook project important?
- What features are essential and are of pedagogical significance?
- What resources are required for this project in terms of time commitment, funding, and team support?
- What open platforms will be used to host the book?
- How to maintain the book in the post-publication stage?

As of 2019-2020, there were limited OER on thermodynamics [8-10] and on relevant engineering subjects in general. The proposed open textbook aims to focus on the most fundamental topics of classical thermodynamics, suitable for a 3-credit, entry-level undergraduate course. During the planning phase, I secured the UBC Okanagan OER Grant to fund my project, hired student collaborators, and consulted with UBC Open Education Librarians to explore various resources available to faculty members for developing OER. My vision for the resulting textbook is a concise, practical, accessible, pedagogically sound, and user-friendly book on introductory thermodynamic. To achieve these goals, I developed an open authoring matrix to frame my work and break it down into tangible tasks, as shown in Table 1. I also used the backward design approach to organize the book content and design its essential features:

1. Each chapter includes clear learning objectives and a concise review section.
2. Each chapter includes step-by-step solved examples and interactive practice problems written in H5P format, as shown in Figure 1. H5P is an abbreviation for HTML5 Package, a free and open-source software that enables the creation, sharing, and reuse of interactive HTML5 content such as quizzes, presentations, and interactive videos. Table 2 includes the number of H5P questions in each chapter. These questions are multiple choice or true/false questions intended for learners to review key concepts and perform self-assessment.
3. The book includes thermodynamics tables of common fluids.

4. The book is easy to navigate.
5. All equations are of high resolution and can be enlarged in a pop-out window, as shown in Figure 2.
6. All images can be enlarged and include alt text for improved accessibility.
7. The book includes a glossary of key terms, and all glossary terms can be displayed in a pop-out window by clicking on or hovering over the term, as shown in Figure 2.

Table 1: Open textbook authoring matrix

Stage	Tasks	Level of involvement			Key
		Minimal	Moderate	Extensive	
Planning	Literature review			A	A: author
	Securing resources: funding and team			A	
	Organizing course notes (if available)			A	S: student collaborators
	Consultation with open education librarians		S	A	
	Defining the scope and audience			A	L: open education librarians
Developing	Selecting open license, open platform and book style	S	L	A	
	Creating book style guide		A	L	E: educational consultant
	Creating and organizing content: chapter by chapter	S		A	
	Searching and documenting open licensed graphs		A	S	
	Creating tables and LaTeX equations		A, E, L	S	
	Creating H5P questions		S	A	
	Formatting and editing	E	A, L	S	
	Evaluating accessibility features			A	
Publishing	Creating book release plan			L	
	Selecting and publishing on open repositories			A	
Post-publishing	Updating book content			A	

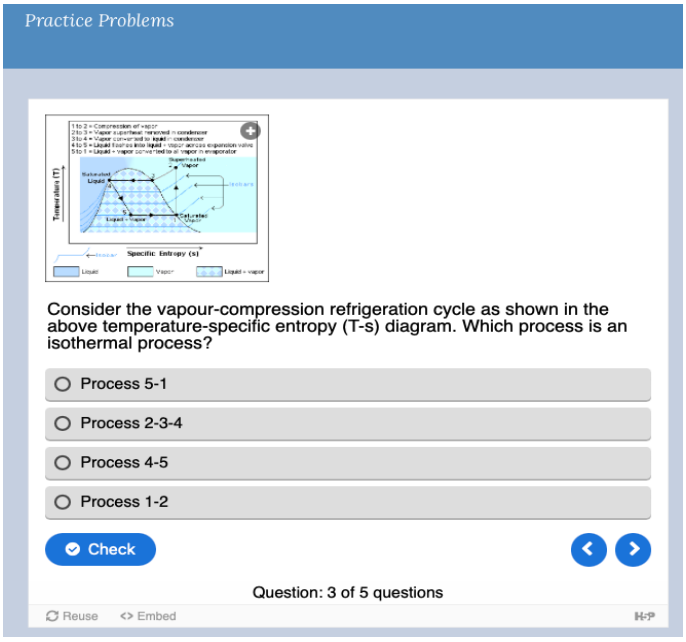

Figure 1: Sample practice problem written in H5P

Developing

The book contains six chapters (as shown in Table 2), which were developed based on my existing teaching modules for thermodynamics. During the development phase, I put a significant amount of effort into writing and revising the details of each chapter while ensuring that all materials were open licensed. For example, thermodynamics tables and charts were not generally available with open licenses; therefore, they had to be generated. I extracted data from the NIST Chemistry WebBook [11] to create tables of thermodynamic properties of fluids. All example calculations in the book are based on these tables. While some challenges were specific to the discipline, there are important considerations applicable to most open textbook development, as listed below.

- *Creating a book style guide*. A book style guide provides a set of consistent guidelines for formatting and presenting information in the book to ensure consistency in its visual and structural elements. This step is particularly important if the open book involves many authors and contributors. At the beginning of the developing phase, UBC Open Education librarians helped us create a book style guide, which my students and I used throughout the book development to help reduce errors, inconsistencies, and ambiguity. A well-designed and well-implemented style guide can enhance the quality and effectiveness of an open textbook and potentially save the authors and editors a tremendous amount of time.
- *Documenting open licensed materials*. All materials presented in an open textbook, including figures, charts, and tables, must have open licenses and must be properly attributed. During the development phase, a significant amount of effort was devoted to finding or generating figures and graphs that are openly licensed. To ensure that proper attribution was given and to facilitate organization and validation of sources for these materials, I used an attribution tracker, as shown in Table 3 to record the open licensed materials used in this book. This practice is essential to help the authors to organize, validate, and track the sources of the materials and to support the broader goals of open education.
- *Improving accessibility through design*. Accessible open textbooks can benefit a wide range of learners, including those who may not have a diagnosed disability but still benefit from alternative formats or features that enhance their learning experience. In developing this book, I followed the guidelines from UBC's OER Accessibility Toolkit [12], which are developed on the principles of Universal Design for Learning. It is important that authors understand the opportunities and limitations of their chosen open authoring platform and design the desired accessibility features accordingly at the initial stage of the development phase. This book was written on Pressbooks. All images are designed with Alt-Text describing the content of the image and hyperlinks linking the book images to their source images of higher resolutions. All equations are written in LaTeX and are rendered using MathJax. They can be displayed as high-resolution, accessible equations in pop-out windows, as shown in Figure 2. The book includes an accessibility statement listing all of its accessibility features.

Publishing

The open textbook, *Introduction to Engineering Thermodynamics*, has been published on BCcampus Pressbooks, a B.C./Yukon open authoring platform hosted by BCcampus. Users can access the book online or download it in various formats, such as PDF, EPUB, Pressbooks XML, etc. During this phase, UBC Open librarians created a book release plan that highlights relevant OER repositories, such as UBC cIRcle, OER Commons, Open Textbook Library, and Merlot for me to share and upload my open textbook. Additionally, I have promoted it to colleagues and students and shared it on social media. One of the advantages of an open textbook is that authors can continue to update and revise the book after its publication. Since September 2022, I have periodically reviewed the book to correct typos and made minor revisions to improve its clarity or visual presentation.

Table 2: Organization of book content

Chapter	**Topics**	**Number of H5P questions**
1	Basic Concepts and Definitions	19
2	Thermodynamic Properties of a Pure Substance	35
3	Ideal and Real Gasses	18
4	The First Law of Thermodynamics for Closed Systems	31
5	The First Law of Thermodynamics for a Control Volume	24
6	Entropy and the Second Law of Thermodynamics	71

Table 3: Attribution tracker

Author	Source (Website or URL)	License and Attribution	Location in the textbook	Alt Text	Figure # & caption	File name and location	Notes

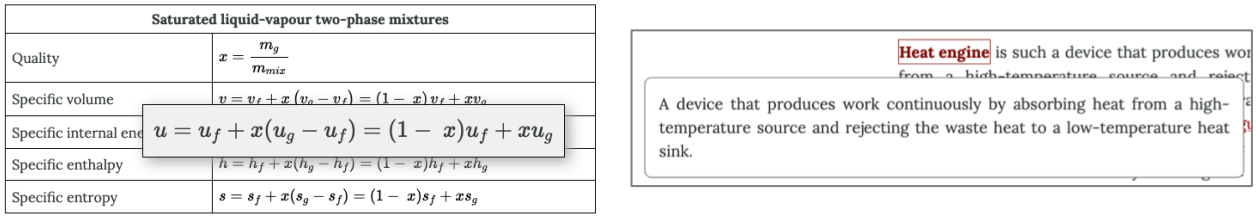

Figure 2: Pop-out equations and glossary term for accessibility

Student survey in a course adoption

The open textbook, *Introduction to Engineering Thermodynamics*, has been adopted by a colleague as a supplementary text for APSC 252 Thermodynamics I at UBC Okanagan in Fall 2022. This 3-credit course is offered to all second-year students in the mechanical, electrical, civil and manufacturing programs at UBC Okanagan. A survey was conducted to collect students' feedback on using the book and their perceptions of OER in engineering courses.

A total of 41 students participated in the survey, with mechanical and electrical engineering students accounting for more than 30% and 40% of the participants, respectively, while the remaining students were from the civil and manufacturing programs. Around 73% of the participants take 5 to 6 courses per term, and approximately 48% and 33% of the participants have GPAs (Grade Point Average) of A and B, respectively, across all their courses. Among all the participants, less than 10% of the students purchased commercial textbooks for APSC 252, while over 90% didn't. The survey also asked the students about how the cost of textbooks affects their purchasing decisions in general. The majority of the students choose to download free books from the internet (about 40%), buy used books (about 22%) or share textbooks with classmates (about 12%), while only 5% of the students purchase new books, see Figure 3. Approximately 35% of the participants indicated that the cost of textbooks had negatively impacted their academic performance in the past.

Figure 3: Impact of textbook cost on student purchasing decisions

Figures 4 to 5 show students' prior experience with OER and their desire for OER in engineering courses in general. It is worth noting that over 75% of the students had never heard of OER before using the open textbook, *Introduction to Engineering Thermodynamics*, and over 90% of students expressed a desire for more OER in engineering courses. A general search of open repositories reveals limited collections on engineering topics, indicating the need for further work in this area.

The survey solicited students' experiences and feedback on the open textbook *Introduction to Engineering Thermodynamics*. Figure 6 illustrates that students utilized the book for a variety of purposes, with the top three being reviewing key concepts to prepare for quizzes and exams, clarifying misconceptions, and practising interactive problems for self-assessment. Notably, many students did not read the book before attending lectures. Figure 7 shows the book features that students appreciated the most, with the top three being no cost, ability to download, and immediate access. Among all other features, students ranked the example problems and detailed solutions, interactive problems, and key equations the highest. In general, the book received positive feedback from students, with approximately 17% of students rating the quality of the

book as excellent and 66% as above average. A detailed analysis of the student comments also identified areas for improvement, such as the need for more diagrams to enhance visual understanding and additional practice problems to promote learning and self-assessment.

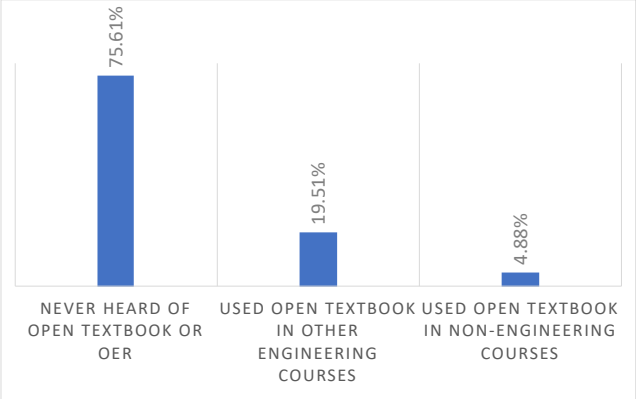

Figure 4: Student prior experience with OER

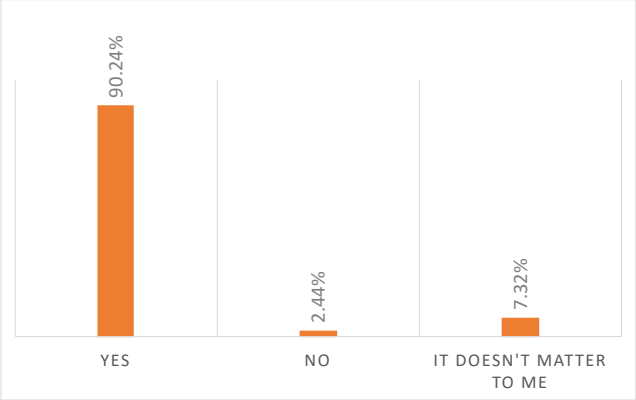

Figure 5: Student desire for OER in engineering courses

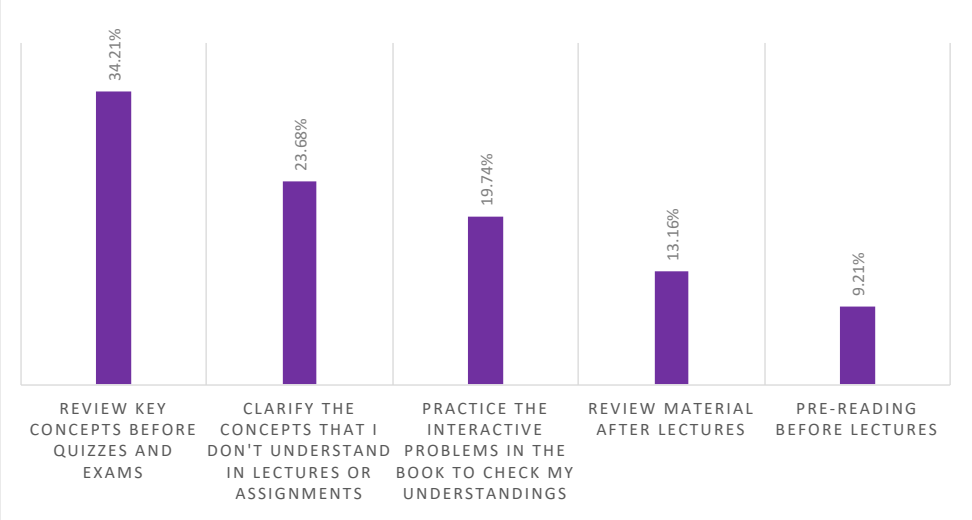

Figure 6: Student use of the open textbook *Introduction to Engineering Thermodynamics*

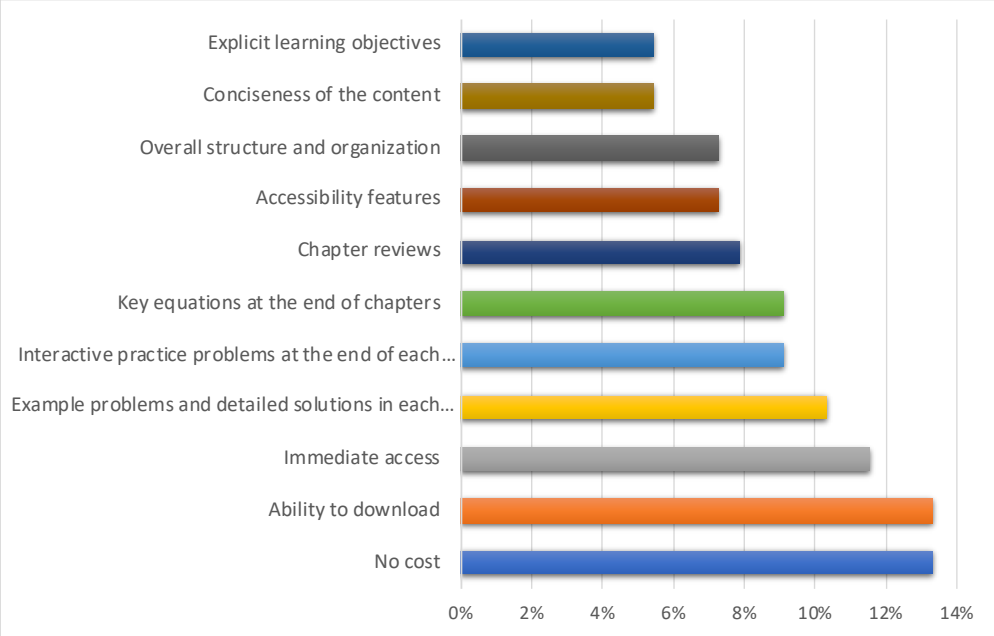

Figure 7: Book features that students appreciated the most

Conclusion

Thermodynamics is a fundamental course in many engineering programs. This paper details the process of creating the open textbook, *Introduction to Engineering Thermodynamics*, and reports the results of a survey conducted among the first cohort of engineering students who used the open textbook. The majority of students had a very positive view of the book and highly valued its various features in supporting their learning. The survey also revealed a strong interest in OER among engineering students and a demand for further development in this area. While writing an open textbook can be challenging, proper planning and good time management can make the work manageable and rewarding, especially when considering the potential benefits for students and a wider community of users. The open authoring process itself is a collaborative and reflective experience, providing authors with a new avenue for innovative teaching and pedagogical development. During this process, institutional support plays a crucial role in motivating faculty to create and/or adopt OER. In this project, I received strong support from UBC Okanagan including funding and assistance from librarians, which made completion of the work possible. Since the publication of the book, I have received various inquiries from colleagues, opening up opportunities for ongoing collaboration and development of OER materials.

Acknowledgement

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