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Development and Use of Open Educational Resources in an Undergraduate Heat and Mass Transfer Course

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Abstract

Higher education costs have been increasing more rapidly than inflation over the last few decades. One way to decrease textbook cost is to use open educational resources (OER), which are materials licensed in a way that allow everyone to engage in the “5R activities”: retain, reuse, revise, remix and redistribute. The most significant benefits of using OER or other no-cost digital materials instead of traditional textbooks is cost savings to students and the ability of all students to have access to the course materials on the first day of class. Studies have investigated faculty and student perceptions of open course materials, and most have had positive experiences with them. Several studies have indicated that students in courses using OER either achieved the same learning outcomes or show improved learning outcomes compared to courses that required traditional textbooks. This paper describes the use of OER and other no-cost digital materials in an undergraduate heat and mass transfer course, as well as the development of instructor-created videos. The main resources include an electronic textbook available at no charge and openly licensed videos. Compared to a previous offering of the course that used a traditional textbook, there was a statistically significant improvement in course performance on two module-level outcomes. A survey at the end of the course indicated that students found the no-cost digital textbook to be about the same quality as or better than the quality of the textbooks in their other courses. Overall, students reported using the textbook in this course more frequently than textbooks in a typical course.

Introduction

Higher education costs have been increasing more rapidly than inflation over the last few decades. From 2002 to 2012, tuition, fees, and textbook prices increased at a rate of 3 times the rate of inflation [1]. These increasing costs and a complex financial aid system contribute to students taking longer to earn a degree or to leave school without a degree [2]. One way to decrease textbook cost is to use open educational resources (OER), which are licensed in a way that allow everyone to engage in the “5R activities”: retain, reuse, revise, remix and redistribute [3]. These resources can include textbooks, online modules, videos, and other digital content. Typically, these resources are licensed with a Creative Commons license, which require attribution to the author and allow the creator to determine if adaptations or commercial uses of the work are allowed.

A significant benefit of using OER instead of traditional textbooks is the cost savings to students. Another benefit of using no-cost digital materials is that all students have access to the course materials on the first day of class. A recent study in which nine courses replaced traditional textbooks with open materials indicated that more students accessed the digital open course materials than had previously purchased the traditional textbooks [4].

Studies have investigated faculty and student perceptions of open course materials, and most have had positive experiences with them [5], [6]. Most faculty and students surveyed found the OER to be of the same or higher quality than traditional textbooks they had previously used [7]. Several studies have indicated that students in courses using OER either achieved the same learning outcomes or showed improved learning outcomes compared to courses that required traditional textbooks [4], [6], [8]–[10]. Additionally, the use of OER has been shown to improve course grades and increase retention at greater rates for Pell Grant recipients and part-time students [8].

Despite the benefits of OER, there is still a lack of awareness about OER and many courses require traditional textbooks. The efforts to create open textbooks has largely been focused on large-enrollment introductory courses, such as calculus, statistics, chemistry, biology, physics, psychology, and economics. Fewer resources are available for upper-level course topics. Some challenges cited by engineering faculty in the adoption of OER include unclear processes to revise materials to better fit course goals, lack of available material especially for upper-level courses, and the time and cost involved for faculty to create and customize materials [11].

This paper describes the use of OER and other no-cost digital materials in an undergraduate heat and mass transfer course, as well as the development of instructor-created videos, to ensure that all students have access to the course materials from the first day of the course. The goals of this study were to determine student perceptions of the course materials and to compare student performance to a previous course offering using a traditional textbook.

Pedagogical Approach/Methodology

The focus of this project is an undergraduate 3-credit-hour heat and mass transfer course. It is a required course in the mechanical engineering curriculum and requires a fluid mechanics course as a prerequisite. The course had previously been offered twice in a blended format by the same instructor [12]. In the revised Spring 2020 course using OER and other no-cost digital materials, the same course objectives and a similar module structure were used as in previous offerings of the course. The online portion of the course was delivered asynchronously through the Canvas learning management system.

For the 16-week semester, the blended course design called for 8 required face-to-face meetings of 75 minutes each, in addition to the final exam period. The course material was organized into 14 modules (Table 1), with each module taking approximately one week. In some weeks, the instruction was completely online; a combination of online and face-to-face instruction was planned for other weeks. Due to the COVID-19 pandemic, the course was transitioned to a fully online format for Module 10 through the end of the course.

Some repositories for open textbooks include OpenStax [13], the Open Textbook Library [14], and the OER Commons [15]. Sources of other OER include MERLOT [16] and Saylor Academy [17]. Several OER for engineering courses were found, including *Engineering Thermodynamics – A Graphical Approach* by Urieli [18] and the University of Oklahoma Engineering Media Lab eCourses [19]. Some OER relevant for heat and mass transfer topics were found at Saylor Academy [20], [21], TU Delft OpenCourseWare [22]–[24], and MIT OpenCourseWare [25]–[27]. A start to an open heat transfer textbook is available at Wikibooks [28]. Selected physical constants and conversion factors are available in the "Intermediate Heat and Mass Transfer" course from MIT OpenCourseWare [25]. Physical properties of fluids are available in the NIST Chemistry WebBook [29]. No comprehensive open textbook that would be suitable for this course was found.

Table 1. Organization of course topics by module.

Module	**Topics**
1	Modes of heat transfer
2	Heat transfer rate in steady-state one-dimensional conduction
3	Temperature distribution in steady-state one-dimensional conduction
4	Temperature profiles
5	Steady-state two-dimensional conduction (fins and shape factor method)
6	Lumped capacitance method for unsteady conduction
7	Unsteady conduction in finite & semi-infinite solids
8	Introduction to convective heat and mass transfer
9	Boundary layer analogies for convective heat and mass transfer
10	Convection in external and internal flows
11	Free convection
12	Radiation heat transfer
13	View factor for radiation heat transfer
14	Mass diffusion

Several open courses referenced *A Heat Transfer Textbook* by Lienhard and Lienhard [30]. The authors hold the copyright, so this is not OER, but the authors have made the book available electronically at no charge. Since one main goal of the project was to reduce the cost of required course materials, it was decided to use this no-cost digital textbook as the main textbook for the Spring 2020 course while other OER materials were planned and created for this course. Therefore, the instructor's efforts to create content shifted to producing short videos and planning to eventually create an open textbook for the course. The textbook that was previously used in the course, *Fundamentals of Heat and Mass Transfer* by Bergman *et al*. [31], was listed on the syllabus as an optional recommended text. The instructor continued to use some problems from this textbook as example problems, both in class and in previously created videos. Table 2 gives a summary of OER and no-cost digital materials used during the course. In addition to *A Heat Transfer Textbook*, major sources of course material were screencast videos, simulations, and multiple-choice conceptual questions (ConcepTests) produced by the Department of Chemical and Biological Engineering at the University of Colorado Boulder (CU) [32]–[34], licensed under a Creative Commons Attribution-ShareAlike 4.0 International License [35]. Instructor-produced videos created for this project are available at go.iu.edu/2i20.

Module 1 (Modes of Heat Transfer), a brief introduction to conduction, convection, and radiation, was primarily completed during a face-to-face class meeting during the first week of the semester. In addition to in-class activities, students were provided with an optional reading assignment, Section 1.3 "Modes of heat transfer" from *A Heat Transfer Textbook*.

The work for Module 2 (Heat Transfer Rate in Steady-State 1-D Conduction) was completed entirely online. Most modules included guided practice assignments, which were meant to prepare students in a flipped classroom for the group activities [36], [37]. These assignments typically involved reading, watching videos, and responding to questions. The guided practice assignment at the beginning of this module used the following resources: Section 2.1 "The heat conduction equation" and Section 2.3 "Thermal resistance and the electrical analogy" from *A Heat Transfer Textbook*, and the CU screencast video "Thermal Circuits Introduction."

Table 2. OER and other no-cost digital materials used in the course.

Module	**Resources**
1: Modes of Heat Transfer	*A Heat Transfer Textbook*: Section 1.3
2: Heat Transfer Rate in Steady-State 1-D Conduction	• *A Heat Transfer Textbook*: Sections 2.1 and 2.3 • CU screencast videos: "Thermal Circuits Introduction" and "Radial System Example" • Instructor-produced videos: "Thermal Resistance" and "Composite Wall Example" • CU ConcepTests
3: Temperature Distribution in Steady-State 1-D Conduction	• *A Heat Transfer Textbook*: Sections 2.1, 2.2, 4.1, and 4.2 • CU screencast video: "Heat Equation Derivation" • CU ConcepTests
4: Temperature Profiles	• *A Heat Transfer Textbook*: Sections 2.1, 2.2, and 4.1 • CU simulation: "Steady-State One-Dimensional Heat Transfer in a Plane Wall" • Instructor-produced video: "Boundary Conditions" • CU screencast video: "Internal Heat Generation"
5: Steady-State 2-D Conduction	• *A Heat Transfer Textbook*: Sections 4.5 and 5.7 • CU screencast video: "Introduction to Fins" • CU simulation: "Temperature Profile in a Fin"
6: Lumped Capacitance Method for Unsteady Conduction	• *A Heat Transfer Textbook*: Section 5.2 • CU screencast videos: "Lumped Capacitance Introduction" and "Lumped Capacitance: Temperature of a Sphere"
7: Unsteady Conduction in Finite & Semi-Infinite Solids	• *A Heat Transfer Textbook*: Sections 5.3, 5.5, and 5.6 • CU screencast videos: "Introduction to Plane Wall with Convection", "Plane Wall with Convection Example", and "Modeling Heat Transfer along a Semi-Infinite Medium" • Instructor-produced video: "Rod Centerline Temperature"
8: Introduction to Convective Heat and Mass Transfer	• *A Heat Transfer Textbook*: Section 6.1 • CU screencast videos: "Thermal Boundary Layers Introduction", "Local and Average Heat Transfer Coefficients", and "Normalizing Thermal Boundary Layer Equations" • CU simulation: "Laminar Flow over an Isothermal Flat Plate"
9: Boundary Layer Analogies for Convective Heat and Mass Transfer	• *A Heat Transfer Textbook*: Section 11.5 • Instructor-produced videos: "Dimensionless Parameters for Convection Heat and Mass Transfer" and "Heat and Mass Transfer Analogy"

Table 2 (continued). OER and other no-cost digital materials used in the course.

Module	Resources
10: Convection in External and Internal Flows	• *A Heat Transfer Textbook*: Sections 6.5, 6.8, 7.2, 7.3, and 7.5 • CU screencast videos: "Solving Convection Problems", "Convective Heat Transfer over a Flat Plate", Introduction to Radial Convective Heat Transfer", "Laminar, Fully-Developed Internal Flow Through a Pipe", "Using a Moody Chart", "Internal Flow with Constant Surface Temperature", and "Outlet Mean Temperature" • Instructor-produced videos: "Flat Plate Heat Transfer Rate", "Flat Plate Convection Example", "External Convection for Pipe in Cross Flow", "Surface Temperature of Cylinder in Cross Flow"
11: Free Convection	• *A Heat Transfer Textbook*: Sections 8.2 and 8.3 • CU screencast videos: "Introduction to Free Convection" and "Free Convection over a Vertical Plate"
12: Radiation Heat Transfer	• *A Heat Transfer Textbook*: Sections 1.3 and 10.1 • CU screencast video: "Properties of Radiative Heat Transfer"
13: View Factor for Radiation Heat Transfer	• *A Heat Transfer Textbook*: Section 10.3 • CU screencast videos: "View Factors", "Net Radiative Heat Transfer Rate from a Surface", and "Radiation Exchange Between Surfaces"
14: Mass Diffusion	• *A Heat Transfer Textbook*: Sections 11.1, 11.2, 11.3, 11.4, and 11.5 • CU screencast video: "Deriving Molar Flux Equations"

The next activity in Module 2 was a page of instructor-written content, instructor-produced videos, the CU screencast video "Radial System Example," and embedded assignments consisting of CU ConcepTests. These assignments were not graded, but students were automatically provided with feedback based on whether a correct or incorrect response was selected. Students could attempt these assignments an unlimited number of times.

The group activity portion of Module 2 consisted of an assignment set up in a discussion board format so that students could post a photograph or scan of their work and view the work of other students. In this assignment, there were two conceptual questions from the CU ConcepTests and one numerical problem. Students were randomly assigned to groups of approximately six students, and each group had their own discussion forum for this assignment. Students were instructed to post their solutions to each question/problem and then to return a day or two later to review any other solutions that had since been posted and to respond with where they agree or disagree with the other posted solutions.

Module 3 (Temperature Distribution in Steady-State 1-D Conduction) was completed partially online and partially during a face-to-face class meeting. The guided practice assignment at the beginning of this module used the following resources: Section 2.1 "The heat conduction equation", Section 2.2 "Steady heat conduction in a slab: method", Section 4.1 "The well-posed problem", and Section 4.2 "General solution of the heat conduction equation" from *A Heat Transfer Textbook*, and the CU screencast video "Heat Equation Derivation." The group activity portion of Module 3 took place during a face-to-face class meeting. Two conceptual questions from the CU ConcepTests were posed and discussed following a Peer Instruction model [38]. Additionally, students worked together to complete two problems.

The work for Module 4 (Temperature Profiles) was completed entirely online. This module followed the same model as Module 2, with the main components being a guided practice assignment, a content page, and an assignment submitted in a discussion board. The guided practice assignment in this module used the following resources: Sections 2.1, 2.2, and 4.1 from *A Heat Transfer Textbook* and the CU simulation "Steady-State One-Dimensional Heat Transfer in a Plane Wall." The next activity in Module 4 was a page with a video created by the instructor and the CU screencast video "Internal Heat Generation."

Module 5 (Steady-State 2-D Conduction) was completed partially online and partially during a face-to-face class meeting. The guided practice assignment at the beginning of this module used the following resources: Section 4.5 "Fin design" and Section 5.7 "Steady multidimensional heat conduction" from *A Heat Transfer Textbook*, the CU screencast video "Introduction to Fins," and the CU simulation "Temperature Profile in a Fin."

The work for Module 6 (Lumped Capacitance Method for Unsteady Conduction) was completed entirely online. The guided practice assignment in this module used the following resources: Section 5.2 "Lumped-capacity solutions" from *A Heat Transfer Textbook* and the CU screencast video "Lumped Capacitance Introduction." The next activity in Module 6 was a page with instructor-created content and the CU screencast video "Lumped Capacitance: Temperature of a Sphere."

Module 7 (Unsteady Conduction in Finite & Semi-Infinite Solids) was completed partially online and partially during a face-to-face class meeting. The guided practice assignment at the beginning of this module used the following resources: Sections 5.3 and 5.5-5.6 from *A Heat Transfer Textbook*, one video created by the instructor, and the following CU screencast videos: "Introduction to Plane Wall with Convection", "Plane Wall with Convection Example", and "Modeling Heat Transfer along a Semi-Infinite Medium."

Module 8 (Introduction to Convective Heat and Mass Transfer) was completed fully online. The guided practice assignment used the following resources: Section 6.1 from *A Heat Transfer Textbook*, the CU screencast videos "Thermal Boundary Layers Introduction" and "Local and Average Heat Transfer Coefficients", and the CU simulation: "Laminar Flow over an Isothermal Flat Plate." The next activity in Module 8 was a page with instructor-created content and the CU screencast video "Normalizing Thermal Boundary Layer Equations."

Module 9 (Boundary Layer Analogies for Convective Heat and Mass Transfer) involved online work and a face-to-face class meeting. The guided practice assignment used the following resources: Section 11.5 "Mass transfer at low rates" from *A Heat Transfer Textbook* and two videos created by the instructor.

Module 10 (Convection in External and Internal Flows) was fully online. The guided practice assignment used Sections 6.5, 6.8, 7.2, 7.3, and 7.5 from *A Heat Transfer Textbook*, and the following CU screencast videos: “Solving Convection Problems”, “Convective Heat Transfer over a Flat Plate”, Introduction to Radial Convective Heat Transfer”, and “Laminar, Fully-Developed Internal Flow Through a Pipe.” A page related to external flows included four instructor-produced videos. A page on internal flows included the following CU screencast videos: “Using a Moody Chart”, “Internal Flow with Constant Surface Temperature”, and “Outlet Mean Temperature.”

Before the course began, Module 11 (Free Convection) was planned to include online work and a face-to-face class meeting. Due to the COVID-19 pandemic, this module was completed fully online. The guided practice assignment in this module used Sections 8.2 and 8.3 from *A Heat Transfer Textbook* and the CU screencast video “Introduction to Free Convection.” The next activity in this module was a page with instructor-created content and the CU screencast video “Free Convection over a Vertical Plate.”

Module 12 (Radiation Heat Transfer) was fully online. The guided practice assignment used Sections 1.3 and 10.1 from *A Heat Transfer Textbook* and the CU screencast video “Properties of Radiative Heat Transfer.”

Module 13 (View Factor for Radiation Heat Transfer) was transitioned fully online. The guided practice assignment used Section 10.3 from *A Heat Transfer Textbook* and the following CU screencast videos: “View Factors”, “Net Radiative Heat Transfer Rate from a Surface”, and “Radiation Exchange Between Surfaces.”

Module 14 (Mass Diffusion) was fully online as planned from the start of the course. The guided practice assignment used Sections 11.1-11.5 from *A Heat Transfer Textbook* and the CU screencast video “Deriving Molar Flux Equations.”

To get insight into textbook purchasing behavior and students’ experience with the course materials, students in the course were asked to complete an anonymous survey during the last two weeks of the course. The survey consisted of Likert-type and open-response questions based on the Project Kaleidoscope student questionnaire [7] and the City University of New York Zero Textbook Cost Student Experience Survey [39]. Qualitative survey responses were transformed using inductive coding.

Results

Seven out of 19 students in the course completed the survey (36.8% response rate). As shown in Figure 1, most of the students who completed the survey reported that they purchased required textbooks most of the time, with the others answering either sometimes or about half the time. No student reported always purchasing required textbooks.

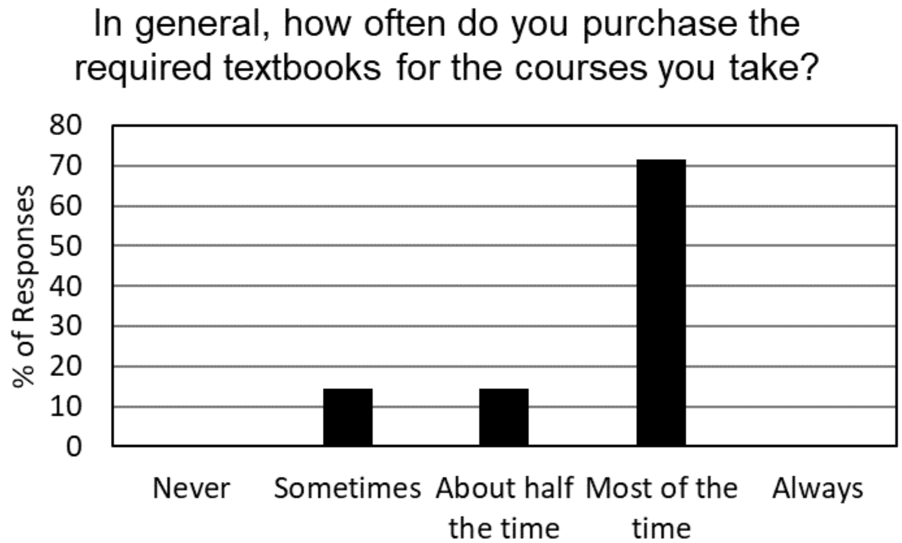

Figure 1. Required textbook purchasing behavior.

Over 70% of the students who responded to the survey indicated that they typically spend over $300 each semester on textbooks, with over 25% reporting that they typically spend more than $500 each semester, as indicated in Figure 2.

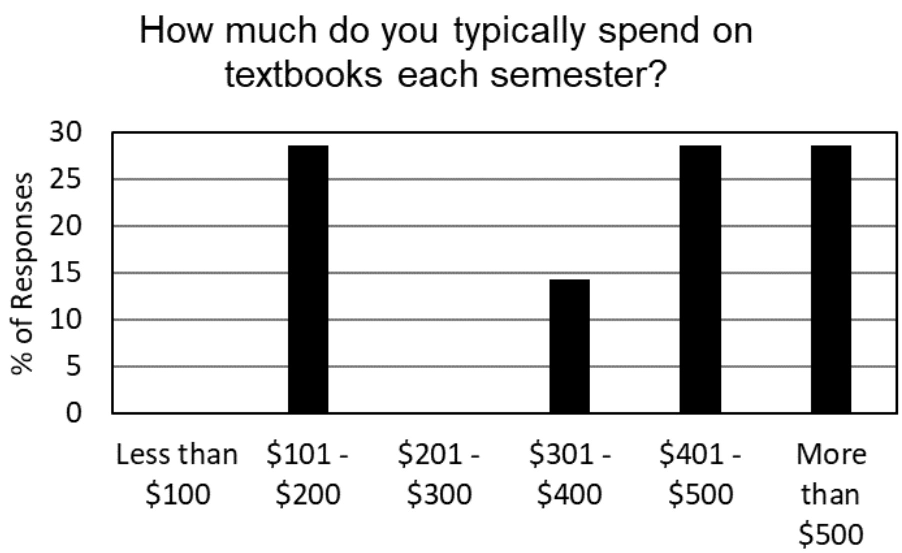

Figure 2. Typical amount spent on textbooks.

In addition to purchasing habits, students were asked how many courses they take each semester. Over 70% reported taking on average six courses each semester; the others reported four or five courses, as shown in Figure 3.

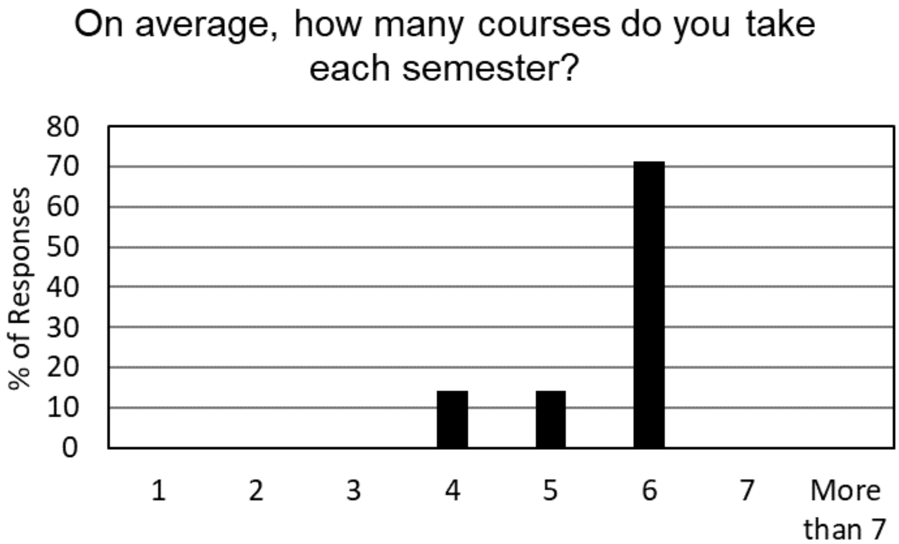

Figure 3. Number of courses taken each semester.

As shown in Figure 4, over 40% of the students reported first accessing the course textbook in the first week of classes.

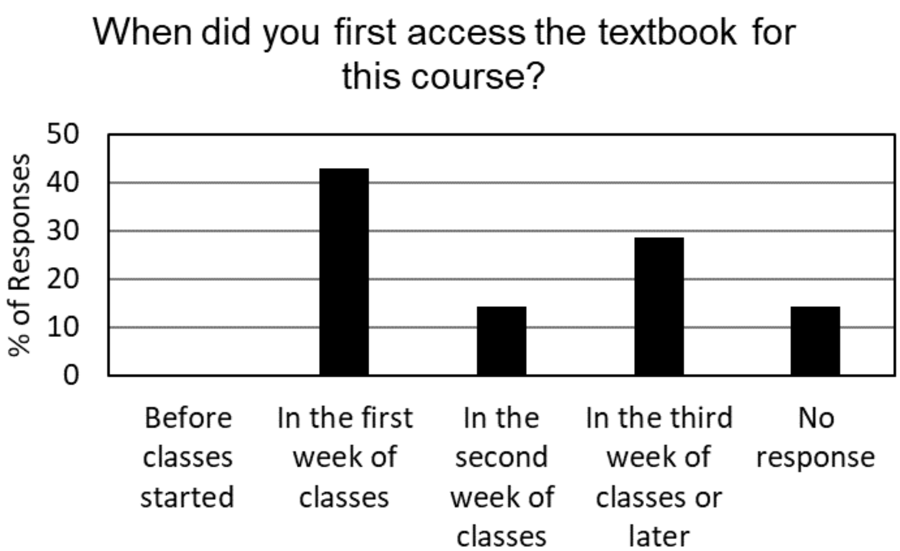

Figure 4. First access to the course textbook.

Students were asked how often they use required texts in a typical course , and how often they used the textbook for this course. As shown in Figure 5, the responses for required text use in a typical course were nearly evenly spread between never, 2-3 times a semester, 2-3 times a month, and 2-3 times a week. In contrast, the majority of responses for textbook use in this course were 2-3 times a week.

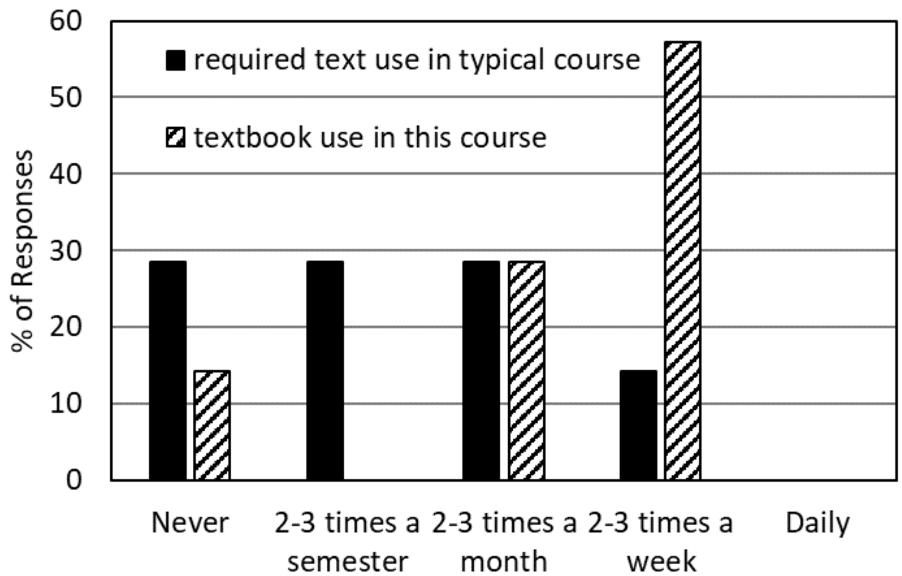

Figure 5. Textbook use in a typical course and this course. Responses to “For a typical course, how often do you use the required texts?” and “How often did you use the textbook for this course during the semester?”

The primary modes of content delivery in the course were reading assignments and videos. As shown in Figure 6, all students reported completing some or all of the required reading/viewing for this course.

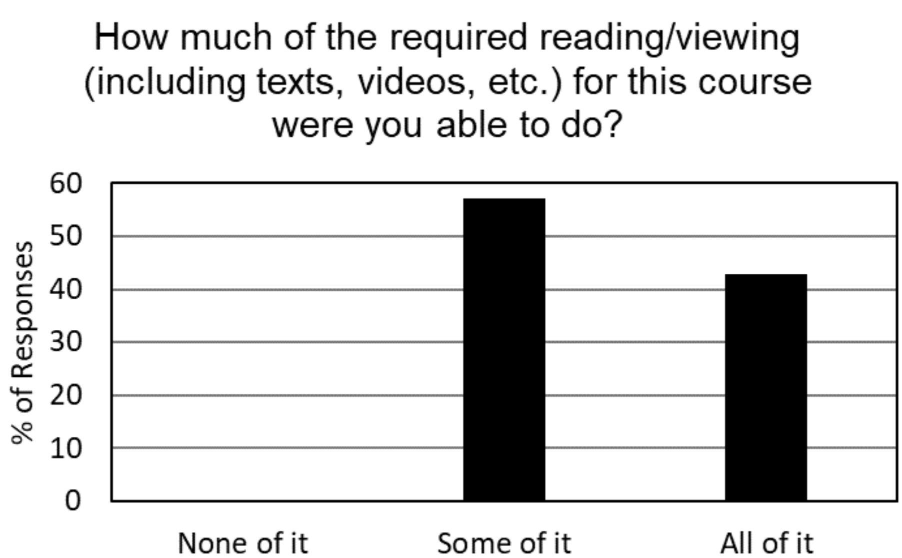

Figure 6. Completion of required reading and viewing for this course.

All 7 students who completed the survey at the end of the course found the no-cost digital textbook to be about the same quality as or better than the quality of the textbooks in their other courses, as shown in Figure 7. In response to a question about what made the quality of this course's textbook better than those in other courses, a student answered, "This book was easy to go through and find exactly what I was looking for."

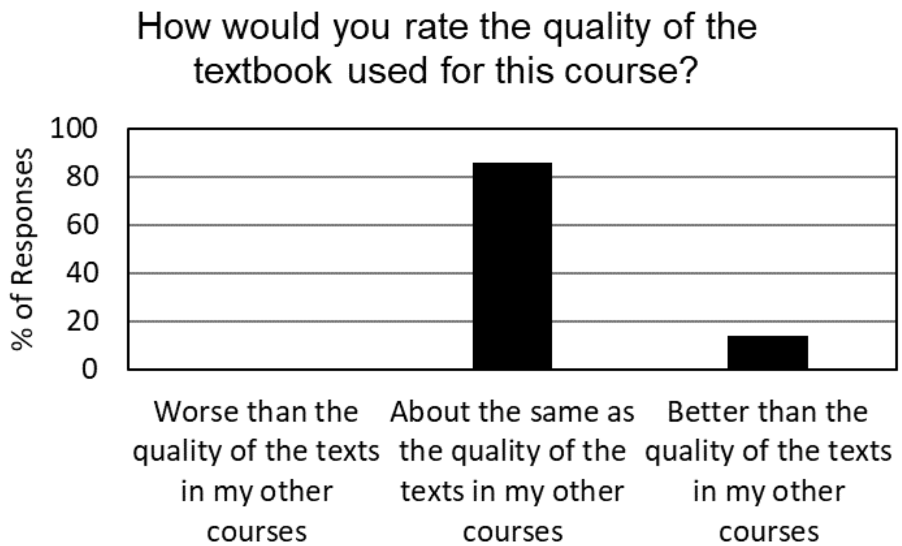

Figure 7. Student perception of textbook quality.

A summary of the themes that emerged from the qualitative survey questions are given in Table 3. Each survey response may have contained more than one theme; therefore, the number of results does not necessarily match the number of survey responses. Five out of the 7 students who completed the survey about the course materials stated the zero cost as a benefit. The main drawback, as stated by 3 students, was difficulty understanding the textbook.

Table 3. Summary of qualitative survey data.

What were the benefits of the free materials (texts, videos, etc.) used in the course?	**What were the drawbacks of the free materials (texts, videos, etc.) used in the course?**
• Free (5) • Easy to access (2) • Searchable • Prefer videos to text	• Difficulty understanding textbook writing and examples (3) • Difficulty finding answers in textbook • None

A standards-based approach to grading was used, with quizzes over specific topics. Quizzes were graded "Pass" or "No Pass" based on specifications determined by the instructor [40]. Students could re-attempt quizzes. The course had 16 students enrolled in the previous academic year (2019). Both courses were taught by the same instructor and used assessments of similar difficulty covering the same topics. A summary of the quiz score data is given in Table 4. Values were determined by converting "Pass" scores to one and "No Pass" scores to zero. Because the

2020 course was converted to a fully online format starting with Module 10, the quizzes over surface radiation and mass diffusion were administered online instead of on paper as in the 2019 course offering. Additionally, all quiz re-attempts in the last six weeks of the course were administered online.

Table 4. Course assessment comparison. The 2019 course used a traditional textbook; the 2020 course used OER and no-cost digital materials.

	2019 (n = 16)		**2020 (n = 19)**			
Quiz Topic	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**	***p***	**Effect Size**
Heat Transfer Modes	0.94	0.24	0.95	0.22	0.90	0.043
Heat Transfer Rate	0.88	0.33	0.89	0.31	0.86	0.062
Temperature Distribution	0.75	0.43	0.79	0.41	0.79	0.094
Temperature Profiles	0.50	0.50	1.00	0.00	0.0015*	2.2
Fins	0.94	0.24	1.00	0.00	0.33	0.56
Shape Factor	1.00	0.00	1.00	0.00	-	-
Lumped Capacitance	0.69	0.46	0.95	0.22	0.06	0.78
Finite Solid	0.69	0.46	0.68	0.46	0.98	-0.0071
Semi-infinite Solid	0.94	0.24	1.00	0.00	0.33	0.56
Convection Equations	0.94	0.24	0.95	0.22	0.90	0.043
Boundary Layer Analogies	0.94	0.24	0.79	0.41	0.21	-0.45
External Flow	0.88	0.33	0.95	0.22	0.48	0.27
Internal Flow	0.38	0.48	0.89	0.31	0.0014*	1.3
Free Convection	0.81	0.39	0.89	0.31	0.51	0.24
Radiation	0.94	0.24	1.00	0.00	0.33	0.56
Surface Radiation	0.81	0.39	0.89	0.31	0.51	0.24
View Factor	0.94	0.24	0.79	0.41	0.21	-0.45
Mass Diffusion	0.44	0.50	0.63	0.48	0.27	0.40

*significant at $p<0.05$ level

No significant difference was found for student performance on quizzes over most course topics. However, a statistically significant ($p<0.05$) improvement was found for student performance on quizzes over conduction temperature profiles and forced convection in internal flow in the course that used OER and other no-cost digital materials compared to the previous course offering that used a traditional textbook.

Several limitations exist for this study. This study considers a single offering of a course with an enrollment of 19 students, and the survey response rate was 36.8%. The course assessment data do not account for other differences in the two offerings of the course, such as demographics, student performance in prerequisite courses, or other factors external to the course. After the course shifted to a fully online format, some quizzes that had previously been completed on paper during on-campus class meetings were administered online.

Conclusions

An undergraduate heat and mass transfer course was revised using a no-cost digital textbook and OER as the main sources of course content. Videos created by the instructor, as well as other openly licensed videos, were used. Students reported using the textbook in this course more often than in a typical course and found the quality of the textbook to be about the same as texts in other courses. Compared to a previous course offering using a traditional textbook, students scored better on two module-level assessments, on the topics of conduction temperature profiles and forced convection in internal flow. Future work includes writing chapters for an open textbook aligned with the learning outcomes for this course and gathering more student feedback on the course materials.

Acknowledgment

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References

[1] U. S. Government Accountability Office, "College Textbooks: Students Have Greater Access to Textbook Information," Jun. 2013. Available: https://www.gao.gov/products/GAO-13-368.

[2] S. Goldrick-Rab, *Paying the Price: College Costs, Financial Aid, and the Betrayal of the American Dream*. Chicago, IL: University of Chicago Press, 2016.

[3] D. Wiley, "Defining the 'Open' in Open Content and Open Educational Resources." [Online]. Available: http://opencontent.org/definition/. [Accessed: 06-Nov-2018].

[4] A. Feldstein, M. Martin, A. Hudson, K. Warren, J. Hilton, and D. Wiley, "Open Textbooks and Increased Student Access and Outcomes," *European Journal of Open, Distance and E-Learning*, vol. 2012, no. II, 2012. Available: https://www.eurodl.org/?p=archives&year=2012&halfyear=2&article=533.

[5] T. J. Bliss, J. Hilton, D. Wiley, and K. Thanos, "The cost and quality of online open textbooks: Perceptions of community college faculty and students," *First Monday*, vol. 18, no. 1, Jan. 2013. Available: https://doi.org/10.5210/fm.v18i1.3972.

[6] J. Hilton, "Open educational resources, student efficacy, and user perceptions: a synthesis of research published between 2015 and 2018," *Education Tech Research Dev*, Aug. 2019. Available: https://doi.org/10.1007/s11423-019-09700-4.

[7] T. J. Bliss, T. Robinson, J. Hilton, and D. Wiley, "An OER COUP: College Teacher and Student Perceptions of Open Educational Resources," *Journal of Interactive Media in Education*, vol. 2013, no. 1, Feb. 2013. Available: http://doi.org/10.5334/2013-04.

[8] N. B. Colvard, C. E. Watson, and H. Park, "The Impact of Open Educational Resources on Various Student Success Metrics," *International Journal of Teaching and Learning in Higher Education*, vol. 30, no. 2, pp. 262–276, 2018. Available: http://www.isetl.org/ijtlhe/pdf/IJTLHE3386.pdf.

[9] J. Hilton, "Open educational resources and college textbook choices: a review of research on efficacy and perceptions," *Education Tech Research Dev*, vol. 64, no. 4, pp. 573–590, Aug. 2016. Available: https://doi.org/10.1007/s11423-016-9434-9.

[10] V. Clinton and S. Khan, "Efficacy of Open Textbook Adoption on Learning Performance and Course Withdrawal Rates: A Meta-Analysis," *AERA Open*, vol. 5, no. 3, Jul. 2019. Available: https://doi.org/10.1177%2F2332858419872212.
[11] T. Anderson, A. Gaines, C. Leachman, and E. P. Williamson, "Faculty and Instructor Perceptions of Open Educational Resources in Engineering," *The Reference Librarian*, vol. 58, no. 4, pp. 257–277, Oct. 2017. Available: https://doi.org/10.1080/02763877.2017.1355768.
[12] J. Mendez, "Development of a Hybrid Heat and Mass Transfer Course," presented at the ASME 2018 International Mechanical Engineering Congress and Exposition, 2018, vol. 5, p. V005T07A012.
[13] "OpenStax.". [Online]. Available: https://openstax.org. [Accessed: 12-Dec-2019].
[14] "Open Textbook Library." [Online]. Available: https://open.umn.edu/opentextbooks/. [Accessed: 26-Dec-2019].
[15] "OER Commons." [Online]. Available: https://www.oercommons.org/. [Accessed: 12-Dec-2019].
[16] "MERLOT." [Online]. Available: https://www.merlot.org/merlot/index.htm. [Accessed: 26-Dec-2019].
[17] "Saylor Academy." [Online]. Available: https://www.saylor.org/. [Accessed: 12-Dec-2019].
[18] "Thermodynamics Graphical Homepage - Urieli - updated 6/22/2015." [Online]. Available: https://www.ohio.edu/mechanical/thermo/. [Accessed: 12-Dec-2019].
[19] "eCourses." [Online]. Available: https://ecourses.ou.edu/home.htm. [Accessed: 12-Dec-2019].
[20] "ME204: Heat Transfer." [Online]. Available: https://legacy.saylor.org/me204/Intro/. [Accessed: 12-Dec-2019].
[21] "ME303: Thermal-Fluid Systems." [Online]. Available: https://legacy.saylor.org/me303/Intro/. [Accessed: 12-Dec-2019].
[22] "Advanced Transport Phenomena," *TU Delft OCW*. [Online]. Available: https://ocw.tudelft.nl/courses/advanced-transport-phenomena/. [Accessed: 12-Dec-2019].
[23] "Fluid Flow, Heat & Mass Transfer," *TU Delft OCW*. [Online]. Available: https://ocw.tudelft.nl/courses/fluid-flow-heat-mass-transfer/. [Accessed: 12-Dec-2019].
[24] "The Basics of Transport Phenomena," *TU Delft OCW*. [Online]. Available: https://ocw.tudelft.nl/courses/basics-transport-phenomena/. [Accessed: 12-Dec-2019].
[25] "Intermediate Heat and Mass Transfer," *MIT OpenCourseWare*. [Online]. Available: https://ocw.mit.edu/courses/mechanical-engineering/2-51-intermediate-heat-and-mass-transfer-fall-2008/. [Accessed: 12-Dec-2019].
[26] "Introduction to Heat Transfer," *MIT OpenCourseWare*. [Online]. Available: https://ocw.mit.edu/courses/mechanical-engineering/2-051-introduction-to-heat-transfer-fall-2015/. [Accessed: 12-Dec-2019].
[27] "Transport Processes," *MIT OpenCourseWare*. [Online]. Available: https://ocw.mit.edu/courses/chemical-engineering/10-302-transport-processes-fall-2004/. [Accessed: 12-Dec-2019].
[28] "Heat Transfer - Wikibooks, open books for an open world." [Online]. Available: https://en.wikibooks.org/wiki/Heat_Transfer. [Accessed: 12-Dec-2019].
[29] "Thermophysical Properties of Fluid Systems." [Online]. Available: https://webbook.nist.gov/chemistry/fluid/. [Accessed: 12-Dec-2019].

[30] J. H. Lienhard, IV and J. H. Lienhard, V, *A Heat Transfer Textbook*, 5th ed. Cambridge, MA: Phlogiston Press, 2019. Available: https://ahtt.mit.edu/.
[31] T. L. Bergman, A. S. Lavine, F. P. Incropera, and D. P. DeWitt, *Fundamentals of Heat and Mass Transfer*, 8th ed. Wiley, 2018.
[32] "Heat Transfer - LearnChemE - Educational Resources for Engineering Courses." [Online]. Available: http://www.learncheme.com/screencasts/heat-transfer. [Accessed: 26-Dec-2019].
[33] "Instructor Resources - LearnChemE - Educational Resources for Engineering Courses." [Online]. Available: http://www.learncheme.com/instructor-resources. [Accessed: 26-Dec-2019].
[34] "Heat Transfer - LearnChemE - Educational Resources for Engineering Courses." [Online]. Available: http://www.learncheme.com/simulations/heat-transfer. [Accessed: 06-Feb-2020].
[35] "Creative Commons — Attribution-ShareAlike 4.0 International — CC BY-SA 4.0." [Online]. Available: https://creativecommons.org/licenses/by-sa/4.0/deed.en_US. [Accessed: 26-Dec-2019].
[36] R. Talbert, *Flipped Learning: A Guide for Higher Education Faculty*. Sterling, VA: Stylus Publishing, 2017.
[37] S. Garcia, "Improving Classroom Preparedness Using Guided Practice," in *Proceedings of the 49th ACM Technical Symposium on Computer Science Education*, New York, NY, 2018, pp. 326–331. Available: https://doi.org/10.1145/3159450.3159571.
[38] C. H. Crouch and E. Mazur, "Peer Instruction: Ten years of experience and results," *American Journal of Physics*, vol. 69, no. 9, pp. 970–977, Aug. 2001. Available: https://doi.org/10.1119/1.1374249.
[39] S. Brandle, S. Katz, A. Hays, A. Beth, C. Cooney, J. DiSanto, L. Miles, and A. Morrison, "But What Do The Students Think: Results of the CUNY Cross-Campus Zero-Textbook Cost Student Survey," *Open Praxis*, vol. 11, no. 1, pp. 85–101, 2019. Available: https://doi.org/10.5944/openpraxis.11.1.932.
[40] L. Nilson, *Specifications Grading: Restoring Rigor, Motivating Students, and Saving Faculty Time*. Sterling, Virginia: Stylus Publishing, 2014.