Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #46730

Evaluating the Effectiveness of an Open-Source Textbook in a Large, Middle-Year Engineering Mechanics Course

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Evaluating the Effectiveness of an Open-Source Textbook in a Large, Middle-Year Engineering Mechanics Course

Abstract
This full paper examines how students interact with a new open-source mechanics textbook to assess its effectiveness. Foundational middle-year engineering courses, like Mechanics of Materials, usually occur in undergraduate engineering students' second and third years after completing the required general coursework (e.g., math, physics, and chemistry). These courses are often characterized by large enrollments, primarily lecture-based formats, and a significant amount of required content. In these types of classes, it is a common practice to require students to buy a homework access code and a textbook to complete the assigned online homework. This requirement places a financial burden on students because of the high cost associated with online access codes and textbooks. Furthermore, engineering students do not spend much time interacting with the textbook and tend to interact with content that helps them complete their homework assignments. Therefore, improving the quality and access to textbooks may be crucial to enhancing student engagement and learning in these foundational courses. This study examines how students utilize and perceive a free, open-access online textbook during its initial implementation in a middle-year engineering course. It also compares this usage with course materials from similar courses that use traditional, cost-based materials. To understand student opinions, we administered pre- and post-surveys, as well as focus groups, in classes that piloted the textbook. We found that students valued the open-access textbook utilized in the course due to its affordability, conciseness, and helpful visual representations. In addition, they appreciated that the book was free. This work can help improve large middle-year engineering classes with respect to the financial strain on students and effective course materials. Findings from this study contribute to ongoing discussions about the role of open educational resources (OER) in alleviating financial strain, improving student engagement, and enhancing learning experiences in engineering education.

Introduction

Engaging in continuous improvement is a good practice for any course, and providing instructors with the tools to make effective data-driven changes can enhance student learning [1]. In engineering education, there has been a call to make changes to curricula and learning experiences to ensure that engineering students are ready to meet the complex challenges of the future [2]. This is compounded by the looming enrollment cliff in higher education, where fewer students are expected to pursue higher education, which includes engineering degrees [3]. Therefore, improving current engineering courses to benefit student learning and student experiences is essential, as institutions can no longer afford to weed students out of engineering.

Foundational middle-year engineering courses usually occur in engineering students' second and third years after they have completed the required general coursework (i.e., math, physics, chemistry). These courses often cause significant barriers to success and persistence in engineering [4]. Additionally, these courses have seen minimal changes over the years. Even though the subject matter remains relatively unchanged, the cost of course materials continues to spiral upward - current textbooks cost over $200 [5]. These classes often require students to purchase textbooks and access codes for online homework systems, which creates a large financial burden for many students. Online textbooks and access codes are often limited to a

single semester and cannot be reused. This means that if students want to continue using the book after the course or need to retake the course, they cannot continue accessing the textbook and homework system. Further, the cost of course materials has repeatedly been found to have a disproportionate and adverse impact on minoritized and Pell-eligible students [6], as well as racial/ethnic minorities and first-generation college students [7]. This is particularly concerning because engineering has historically had low representation of women, racial/ethnic minorities, and first-generation students, so addressing diversity issues in engineering is a national priority [8]. Reducing financial barriers related to course materials could help improve equity and access in engineering.

Improving engineering courses, particularly concerning the cost of course materials, is increasingly important to broaden participation in the current higher education landscape. Engineering programs and course instructors can explore alternative course materials, such as Open Educational Resources (OER), to help minimize financial strain on engineering students. Unfortunately, there is a lack of OER resources in engineering [9], so their use is very rare [5]. This indicates that institutions have an opportunity to invest in the development, adoption, and dissemination of Open Educational Resources in engineering. Investing time and resources into OER can help address financial challenges in engineering and help innovate traditional engineering courses.

At a large R1 institution in the mid-Atlantic region, two instructors teaching Mechanics of Deformable Bodies (also known as Deforms, Mechanics of Materials, Strength of Materials) incorporated a newly written OER Deforms textbook into their course. The textbook was written by a team of mechanics instructors, including members of our author team and the instructors piloting the textbook, to create a resource that is both easy for students to navigate and understand. While the textbook aims to enhance affordability and access through high-quality OER, our team also prioritizes student conceptual learning in mechanics education by incorporating authentic problems.

This study examines how students utilize and engage with an open-access mechanics textbook. We seek to compare how students use this textbook to other large middle-year mechanics courses. The following research questions will guide the study:

> **RQ1:** How do engineering students perceive the financial benefits of using an OER Deforms textbook compared to traditional engineering course materials?
> **RQ2:** How did engineering students' use of academic strategies change from the beginning to the end of the course, where the OER Deforms textbook was used?
> **RQ3:** How do engineering students' opinions of the OER Deforms textbook compare to their experiences with traditional, commercially published engineering textbooks?

Background

OER in Engineering

Open Educational Resources “are learning, teaching and research materials in any format and medium that reside in the public domain or are under copyright that have been released under an open license, that permit no-cost access, re-use, re-purpose, adaptation and redistribution by others” [10]. OERs are valuable because they can eliminate significant financial burdens, making

higher education more accessible and equitable. However, there are still significant improvements that can be made with OER in engineering education; as recently as July 2022, the Engineering Librarian Division of the American Society for Engineering Education released a guide to provide improved access to engineering OER [11], and a special issue in 2014 made recommendations to improve OER initiatives in the field [12].

There are limited OER resources in engineering [9], which leads to their infrequent usage [5]. While there are some OERs available in mechanics education, they tend to focus mainly on Statics. Additionally, the quality and breadth of material in these resources vary significantly, and many of them do not provide instructors with the flexibility to easily adapt the course content to fit their specific context [12]. Moreover, OER often includes a limited number of problem exercises, and there is no centralized resource where engineering instructors can access comprehensive and varied problem sets. This gap makes commercial textbooks particularly attractive, as they typically come with extensive problem banks. Additionally, commercial textbooks with homework systems often feature automated scoring and compatibility with Learning Management Systems, a capability that OER frequently lacks.

Mechanics Education

In order to understand academic strategies and uses of an OER textbook in a course like Deforms, it is important to understand common aspects of mechanics education. Foundational middle-year engineering courses are often characterized by large enrollments, primarily lecture-based formats, and a considerable amount of required content that students must master for subsequent courses. Large, lecture-based courses are not always conducive for students to develop an understanding of complex course content. Large classes rely more heavily on lecture-style teaching, have less active student involvement, and students receive less interaction and feedback from the instructor [13].

In middle-year classes, students develop a “toolbox” of skills needed for subsequent upper-level courses, their capstone design course, and future careers; however, there have been few efforts to create large-scale, innovative change for these courses because of the rigid requirements around the content covered. Individual instructors, programs, and institutions have developed innovative course design practices and teaching approaches for engineering mechanics middle-year courses (i.e., Statics, Dynamics, Deforms). Still, there haven’t been large-scale changes to these classes. Some instructors and programs have tried challenging the common lecture-based format in mechanics courses by flipping the classroom, incorporating in-class quizzes, and adding modules to the course, among other approaches [14], [15], [16], [17]. However, there have been mixed results among these approaches; some found it really improved student performance, while others found minimal improvements. This shows that redesigning middle-year courses can have mixed results. Moreover, widespread change in engineering is stymied [18], [19]. Therefore, there is no universal, easy way to improve foundational middle-year courses. Therefore, improving one aspect of mechanics courses, such as the textbook, could be highly valuable in helping to improve student learning in undergraduate engineering without necessitating a system overhaul.

Engineering Textbooks

In engineering, the textbooks are often verbose, with a high level of technical knowledge, making it difficult for novice students to understand the content. When a textbook emphasizes the comprehensive coverage of topics, it often sacrifices clarity and accessibility, leaving students struggling to connect theoretical concepts to practical applications. Generally, engineering students tend to use the textbook to search for problems rather than utilizing it as a resource to support their conceptual understanding [20]. A study that examined resources used in undergraduate engineering found that textbooks are often transactional [21]; students use them to complete assignments or find answers rather than for deeper learning or conceptual understanding. In higher education, textbooks are often used as a substitute for attending lectures or paying attention to them [22].

Students often view textbooks as tools for completing homework or preparing for exams rather than as a resource to support their conceptual understanding. This issue is particularly concerning in engineering, where developing a strong conceptual understanding is critical for success in upper-level courses. This suggests an opportunity to rethink how engineering textbooks are written and integrated into the curriculum. By prioritizing clarity and alignment with student needs, textbooks can be transformed from transactional tools into effective resources to foster conceptual understanding.

Methods

Participants

In this study, we are investigating how students use and interact with an OER Deforms textbook. For this study, two instructors across three sections piloted the textbook during the Fall 2024 semester, so the participants in this study were students enrolled in Deforms during that semester. It is important to note that the two instructors are also authors of the textbook and were committed to the initial rollout of the textbook. At our institution, Deforms is typically taken by second-year engineering students in the spring semester. However, approximately 30% of students take the course in the fall semester. Each section had 75 to 100 students enrolled. Additionally, multiple engineering majors at our institution require Deforms.

To recruit participants, we used a purposive sampling method [23] to intentionally select participants who were enrolled in Deforms and utilizing the new OER textbook. Two of the authors who were external to the course attended class on the first day of the semester to introduce students to the study. Students were able to self-select into the study; they were informed that their participation was completely voluntary, and anything they shared throughout the research process would not be directly shared with their instructors. Since the textbook was being piloted, our overarching purpose, which we communicated to students, was to collect unbiased feedback that could inform future iterations of the textbook. We contacted the Institutional Review Board at our institution, and they determined that our project did not require students to complete a consent form, but we still chose to collect consent from each of the participants.

In total, we had 184 students who completed the survey at the beginning of the semester and 102 students who completed the survey at the end of the semester. Additionally, we had 11 students participate in three different focus groups throughout the semester. Although we collected

demographic information from the participants, we did not analyze the data by demographics so we chose not to include them in our paper.

Data Collection

At the beginning of the semester, we conducted a survey to understand students' concerns about the cost of course materials and how this has impacted their education. We asked students if they were concerned about the cost of course materials, as well as if their academic experience had been impacted by the cost of these materials. The specific question and rating scale can be found in Table 1 in the appendix. We also included an open-ended question that allowed students to elaborate on how the cost of course materials influenced their academic progress.

In addition to understanding students' views on the financial aspect of course materials, we also sought to understand their use of these materials. For this, we listed common academic strategies students used and asked *how often* they used each strategy, and *how helpful* each strategy was in a similar class, Statics, a prerequisite course. Understanding students' academic strategies at the beginning of the semester gave us a baseline understanding of how often they used the textbook in similar courses and how helpful that textbook was. At the end of the semester survey, we asked the exact same questions, but they were related to the academic strategies they used in Deforms. The academic strategies we included are shown in the list below. The list was developed by multiple authors who are current researchers in the field of engineering education.

- Work on provided practice problems (notes, book, homework)
- Read/review notes
- Read the book
- Ask questions during office hours (instructor or TA)
- Email instructor/TA
- Ask questions in class
- Talk to peers/study group
- Utilize university-provided tutoring or privately hired tutors
- Look for instructional examples from resources external to the course
- Look for problem solutions from resources external to the course

The focus groups primarily focused on the textbook. We asked students about their perceptions of the textbook, how they used it, how it compared to other courses, and any areas for improvement they noticed. To complement these discussions, we included a few open-ended questions in the survey at the end of the semester, inviting students to share their overall opinion of the textbook and how it compared to textbooks in their other courses. Although the questions didn’t explicitly ask about commercially published textbooks, students naturally drew comparisons, highlighting key differences in usability, accessibility, and effectiveness.

Data Analysis

The qualitative data, including focus groups and open-ended survey questions, were analyzed using an open coding approach [24]. This step enabled us to identify recurring themes, patterns, and insights related to students’ perceptions and uses of the OER Deforms textbook, as well as the financial benefits of the textbook. The quantitative data was analyzed using descriptive statistics, which is valuable in education research to describe a situation without trying to address relationships between variables [25]. Additionally, the rank of academic strategies was analyzed

using a Mann-Whitney U test to compare differences in students' academic strategies between their reflections on Statics and Deforms, assessing whether certain strategies were ranked higher or lower across the different courses [26]. The analysis results are presented alongside the corresponding research question.

Results

In general, we found that students appreciated the OER Deforms textbook used in the course. We share the results as they relate to each research question.

RQ1 - Financial Benefits

Our first research question focuses on how engineering students perceive the financial benefits of using an OER Deforms textbook compared to traditional engineering course materials. For reference, the textbook and access code typically required for this course cost $130. At the beginning of the semester, approximately 30% of the students in the study reported that they occasionally or frequently did not purchase required textbooks for their courses due to the cost. Students elaborated on their thoughts about the cost of course materials through an open-ended question on the survey at the beginning of the semester. Some students said that the cost of textbooks did not influence their academic experiences because they have parents, academic scholarships, financial aid, or jobs that help them buy textbooks.

Although some students' academic experience has not been affected by the cost of course materials, many students explained that the cost of textbooks adds additional stress to their lives. For example, many students explained that they need to tighten their budget around the time they need to buy textbooks, which can be illustrated by this student's response,

> It makes budgeting for the first few weeks of school tough. I never know if I am going to need the textbook until the first week, and by then I have already spent money on groceries, gas getting to school, etc. It just throws a bit of a wrench in my budgeting for the first few weeks of back to school.

This was echoed by many students who indicated that the cost of the course materials was an extra financial burden they needed to consider on top of tuition costs, which this student expressed: “It's an extra burden for an already expensive experience.”

In addition to the financial and budget burden that many students experience due to the high cost of course materials, students explained that they often try to find free copies of books when possible or refrain from purchasing the textbook if it is not required for homework. Finding PDF versions of textbooks is a common experience, “The cost of textbooks has made me look to other resources to be [able] to obtain said textbook. For example, looking for it online as a free PDF version.” Even though textbooks can be a great resource, many students may choose not to buy them because of their high cost “Since textbooks are expensive I don’t buy them if it’s not required even though they may help.” Generally, students discussed their frustration about having to purchase a textbook for a course in addition to tuition and fees. They shared alternative strategies to reduce costs, which sometimes involved forgoing the textbook altogether. However, this is not always feasible if a costly homework system is required for the course.

At the end-of-semester survey, students were not directly asked about the cost of course materials for the class ($0). Still, 18% of students shared that they appreciated that the textbook

was free. A few responses from students show their appreciation of the textbook cost: (1) “Absolutely legendary textbook for being free. Better than most textbooks that I pay hundreds of dollars for.” (2) “I really appreciated that the textbook was free, that was a huge help.” (3) “It is on par [with other textbooks] with the benefit of being lower cost, so the value is much greater.”

RQ2 - Academic Strategies

At the beginning of the semester, we asked students to rank the academic strategies they used *most often* and the ones that were *most helpful* in Statics. At the end of the semester, we asked students the exact same question, but this time it pertained to Deforms. To answer this research question, we calculated the average rank for each academic strategy and ordered them from highest to lowest rank.

With respect to Statics, the students felt like working on provided practice problems, reading and reviewing notes, and asking questions during office hours were the academic strategies they used most often, and they were also the most helpful strategies. When reflecting on their Statics class, they ranked reading the book as 8th for what they did most often and 7th for what they felt was most helpful. With respect to Deforms, the students ranked working on provided practice problems, reading and reviewing notes, and asking questions during office hours very highly. However, they ranked reading the book as the 3rd thing they did most often and 5th for what they felt was most helpful. This shows that they utilized the book more in Deforms than they did in Statics. A Mann-Whitney U test revealed that students’ rankings of how often they read the textbook significantly changed from their reflection of Statics to their reflection of Deforms ($W = 8014.5$, $p = 0.017$), indicating that their use of the textbook shifted between courses.

RQ3 - Opinion of OER Deforms Textbook

In the survey and focus groups, we asked students their opinions of the textbook and how they utilized it. In general, most students liked the textbook and provided helpful feedback to improve future versions. This OER Deforms textbook was created for students by providing essential content without unnecessary information, clear images, and user-friendly interfaces. Students recognized this in the focus groups: “ It has a good amount of visualizations, and it's also very user-friendly, like probably the most user-friendly textbook I've used so far, and this one was free, and the other ones were sometimes over a hundred dollars.”

Students recognized that the content was straightforward and easy to digest, which can be shown by one student's reflection, “This material is much more digestible and straightforward. There isn’t any unnecessary information in the textbook, and everything is where it should be. It’s much easier to navigate and it is more concise than [textbooks in] my other classes.” Throughout the focus groups, students really appreciated how straightforward the textbook was, and one student even said that it felt like it was tailored for students, which was further expanded on,

> I think part of what makes it tailored to students is that there's lots of pictures. It seems like it's very heavy on diagrams and photos and kind of like showing what's going on, rather than having to read through large sections of text describing what's going on.

This idea was reiterated by another student, who felt like they could understand the textbook on the first read-through, unlike other textbooks: “... like my physics, textbooks, and other things like that, I'll have a really hard time digesting it without like YouTube videos, but Deforms, I actually have a pretty good time like understanding it.”

Through the focus groups, students also discussed their engagement with the textbook and its impact on their learning. Compared to their other classes, one student recognized that,

> What I'm learning in [the] textbook is what I'm gonna be using in class…I find myself actually using the textbook which you know [that's] a good indicator. But yeah, I find that other textbooks just have too many details that are overcomplicated for someone who's a freshman.

As one student reflected on how the textbook impacted their learning in the course, they commented on the difference between the textbook in this course compared to their other courses,

> I feel much more confident in this course than I did navigating Statics or Dynamics in the past… I feel content. I feel like I'm learning what I need to learn. I'm satisfied in the content that I'm being given.

Student reflections about the textbook in the focus group showed that they felt the textbook supported their learning and increased their confidence.

One of the major limitations of the textbook that students noted was the lack of practice problems. Most textbooks have a bank of problems at the end of the chapter, but this textbook does not. Since this is the pilot version of the textbook, there are only a few worked-out problems throughout the chapter, along with a couple of practice problems at the end. A common academic strategy among students in this type of course is to complete practice problems, as indicated by our survey results; however, this can be challenging when there are limited problems in the textbook. Students pointed out this limitation in their reflection,

> I think the textbook could benefit from having more example problems with worked out [solutions] fully provided. This is not only the best-proven way for students to perform better on tests but also the best way for students to build confidence in their own abilities.

During the focus groups, this was the primary piece of feedback students provided,

> There are not a whole lot of problems. Just very, like, direct problems with good solutions. I do think that there are a lot of people who appreciate having, like, lots of problems to work through. So I feel like [having something] kind of similar to how they do it in a lot of other textbooks where you just have them in the Appendix, or something.

Creating more problems for the textbook is something the textbook team is actively working on, so it is good to know students want more problems and think there are significant benefits to including more practice problems in the textbook.

Discussion

We found that traditional textbooks often impose a significant financial burden on students, leading many to forgo purchasing required course materials, which can negatively impact their learning and academic outcomes. In our study, approximately 30% of students reported not purchasing a textbook due to cost, which, while lower, aligns with another research study, which showed that 66% of students have chosen not to purchase textbooks due to cost [27]. Although there are alternatives to high textbook costs, such as renting a book, students often have no choice but to purchase these required materials due to the associated homework system; otherwise, they cannot complete their assignments. Furthermore, if students rent a textbook, they will not have access to it after the course concludes, which limits the advantages of renting a textbook.

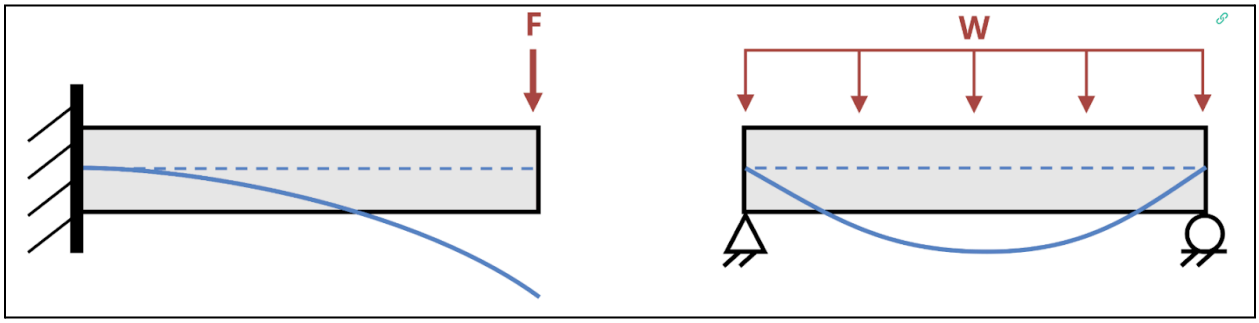
While our end-of-semester survey did not explicitly ask about textbook costs, some students shared that the Deforms textbook was free, highlighting the importance of affordable resources. This concern is underscored by data from the College Board, which estimated in 2020 that the annual cost of textbooks for students could be over $1,200 [28]. This indicates a need for more affordable resources, such as Open Educational Resources. Research that studied student perceptions of an OER textbook in a course found that students appreciated that they could use the textbook at no cost, and it was more engaging than traditional textbooks because it was curated by their instructor [28]. This suggests that our textbook may be limited in its applicability beyond our institution. However, if other instructors who adopt the textbook are able to adjust the textbook to better suit their course or teaching style, it could influence student perceptions.

One of the goals of creating the OER Deforms textbook was to prioritize student learning and conceptual understanding by creating a resource that is easily understandable for students. Conceptual understanding is crucial for engineering students. Developing conceptual understanding is a continuous process, and students enter engineering with vastly different levels of understanding [29]. Students recognized that the pictures and diagrams in the textbook helped their understanding, which aligns with research on visual learning in engineering education. Felder and Silverman highlight that many engineering students are visual learners and benefit from instructional materials that include diagrams, schematics, and other visual representations [30]. By presenting material in an accessible way, the OER Deforms textbook aims to support students in building a strong foundation for success in engineering. Students felt that the textbook was easy to understand, and it had helpful pictures and diagrams to aid in their learning. Future work can investigate whether incorporating this specific textbook had any measurable effect on student learning.

Moreover, the findings from the survey question about academic strategies showed that students turned to the textbook more often in Deforms compared to Statics, and student reflections in the focus group indicated that they felt the textbook supported their learning and increased their confidence. Additionally, students highlighted specific features of the textbook, such as its clear explanations and diagrams, which were particularly helpful for their understanding (An example of the diagrams can be found in Figure 1). Together, these results suggest that the textbook played a significant role in student engagement and learning, reinforcing its value as a resource in the course and highlighting the importance of well-structured, accessible materials to support learning in mechanics education.

Figure 1

Example of the OER Deforms textbook diagrams



Our findings highlight the potential of OER to not only reduce financial barriers but also improve the quality of learning materials in engineering education. Resources like this OER Deforms textbook can play a pivotal role in creating more equitable and effective learning experiences. Additional research is needed to evaluate the long-term and measurable effects on student outcomes, including retention, performance, and engagement, as more institutions and engineering programs investigate OER opportunities. One of the limitations of this study is that we were not able to connect student perceptions of the textbook with learning outcomes, as we did not collect grades or other performance measures. Even if we had collected this data, it would be challenging to determine whether any changes in academic performance were directly related to the textbook, given that many other factors influence student learning and success.

Conclusion

The purpose of this study was to assess how students use and interact with a new OER Deforms textbook. We wanted to compare how students used this OER Deforms textbook to other middle-year mechanics courses. We found that students valued the OER Deforms textbook utilized in the course because of its affordability, conciseness, and helpful visual representations. Middle-year courses in engineering have seen minimal changes over the years; however, these courses often create significant barriers to success and persistence in the field, indicating a substantial opportunity to implement changes that improve access and equity in engineering. Findings from this study contribute to ongoing discussions about the role of OER in alleviating financial strain, improving student engagement, and enhancing learning experiences in engineering education.

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Appendix

Table 1

Survey questions about the cost of course materials

In your academic career, has the cost of required course materials caused you to:					
	Never	Seldom	Occasionally	Frequently	N/A
Take Fewer Courses	☐	☐	☐	☐	☐
Not register for a specific course	☐	☐	☐	☐	☐
Drop a course	☐	☐	☐	☐	☐
Withdraw from a course	☐	☐	☐	☐	☐
Earn a poor grade because you could not afford to buy the textbook	☐	☐	☐	☐	☐
Fail a course because you could not afford to buy the textbook	☐	☐	☐	☐	☐
Not purchased the required textbook	☐	☐	☐	☐	☐