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Development of an Interactive Top Hat Textbook for Engaged Learning

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Dr. Tony Kerzmann's higher education background began with a Bachelor of Arts in Physics from Duquesne University, as well as a Bachelor's, Master's, and PhD in Mechanical Engineering from the University of Pittsburgh. After graduation, Dr. Kerzmann began his career as an assistant professor of Mechanical Engineering at Robert Morris University which afforded him the opportunity to research, teach, and advise in numerous engineering roles. He served as the mechanical coordinator for the RMU Engineering Department for six years, and was the Director of Outreach for the Research and Outreach Center in the School of Engineering, Mathematics and Science. In 2019, Dr. Kerzmann joined the Mechanical Engineering and Material Science (MEMS) department at the University of Pittsburgh. He is the advising coordinator and associate professor in the MEMS department, where he positively engages with numerous mechanical engineering advisees, teaches courses in mechanical engineering and sustainability, and conducts research in energy systems.

Throughout his career, Dr. Kerzmann has advised over eighty student projects, some of which have won regional and international awards. A recent project team won the Utility of Tomorrow competition, outperforming fifty-five international teams to bring home one of only five prizes. Additionally, he has developed and taught fourteen different courses, many of which were in the areas of energy, sustainability, thermodynamics, dynamics and heat transfer. He has always made an effort to incorporate experiential learning into the classroom through the use of demonstrations, guest speakers, student projects and site visits. Dr. Kerzmann is a firm believer that all students learn in their own unique way. In an effort to reach all students, he has consistently deployed a host of teaching strategies into his classes, including videos, example problems, quizzes, hands-on laboratories, demonstrations, and group work. Dr. Kerzmann is enthusiastic in the continued pursuit of his educational goals, research endeavors, and engagement of mechanical engineering students.

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Development of an Interactive Top Hat Text for Engaged Learning

Abstract

Collegiate education requires a multi-faceted instructional approach both within and outside the classroom to effectively build student comprehension and competency. There are well-documented in-class activities that increase student engagement and learning, such as in-person and computer-based think-pair-share activities [1],[2] and polling [3]. There are also complementary out-of-class activities that augment in-class learning by fortifying key concepts. Flipped course formats within traditional synchronous [4]-[6] and asynchronous instruction [7], and more recently the use of Makerspaces [8]-[10] are examples of these activities. An often-overlooked area of out-of-class instruction is the ability to effectively utilize a textbook throughout the various stages of learning. To this end, an interactive textbook was developed in the Top Hat software platform and implemented in a sophomore-level Statics and Mechanics of Materials course. Surveys were conducted to better understand student perceptions of, and interaction and engagement with, an online textbook.

The text was built in a concept-example-question format, based on Cognitive Load Theory (CLT), where concepts were introduced conceptually, graphically and mathematically. This introduction was followed by illustrative examples. Embedded questions tested the understanding of, and competency with, the online textbook material. Thus, within the text alone, students had multiple exposures to the content, reinforcing the conversion of short-term memory to long-term memory recall [11]. Additionally, the text was co-authored by a student who had recently taken the course and who was able to provide insight into which concepts and aspects of the course their peers struggled with.

One of the novel aspects of this text are embedded questions, which bridged in-class and out-of-class instruction. Students were assigned portions of the text as reading assignments, and were required to answer embedded questions. Embedded questions are adaptable by the instructor as to provide help if a student answers incorrectly, to allow multiple answer attempts, to provide instantaneous feedback in the form of showing the correct solution after the last attempt, and to count as participation and/or correctness points. Top Hat's platform tracks student performance and notifies the instructor of questions with low averages such that remedial measures can be introduced at different points in the learning process, such as during class. The implementation of the concept-example-question format, coupled with the uniqueness of Top Hat's embedded question feedback mechanisms, provides a high level of interactivity and engagement not available within conventional texts.

To ascertain the effectiveness of an interactive text on student learning, engagement and satisfaction, a mixed-methods study was performed involving three sections of the course. A survey composed of both open- and closed-ended questions was administered to each section at the end of the semester, and was used to gauge student interest, engagement, and perceptions of the textbook. Preliminary results indicate a high level of student satisfaction and favorable attitudes toward the extent and frequency of interactivity. Students have indicated they feel confident and competent with the course material by having recurrent interaction and instant feedback regarding their comprehension and understanding.

Introduction

Traditional textbooks have been undergoing a transformation in the past two decades, transitioning to digital formats, in part to decrease publishing costs [12], reduce environmental impacts, and increase portability [13]. Most conventional textbooks have been converted to a digital format, such as a PDF, with nothing more than hyperlinking to facilitate navigation. Other texts have been converted to a web-browser based format, and have slowly incorporated basic technological advancements, such as animations and embedded questions, in an attempt to increase interactivity and engagement [14]. With the slow evolution and introduction of interactive texts hosted on web-based platforms, there have been relatively few studies on the efficacy of such texts on student engagement, satisfaction, and performance. Of the few studies which exist, even fewer have been focused on engineering-based texts.

O'Bannon et al. [15] studied student achievement when an interactive, digital textbook was used in place of traditional lectures for specific content in a technology-oriented course. It is noted their platform was based on Apple's iBook Author, which allowed for the incorporation of various types of multimedia, as well as immediate-feedback embedded questions, but only on Apple iOS devices. The study was guided by research questions on student perception of the benefits and challenges of using an interactive text, and how the use of such text affects student achievement. Their findings indicated the group utilizing the digital text performed better in post-test assessments in comparison to pre-test assessments than the group instructed via traditional lectures. Student perception of the text in terms of ease of understanding, providing assistance toward their evaluated assignment, ability to provide a new avenue to learning, increasing motivation and excitement toward learning, increasing attention, instruction efficiency and interest in the course, was favorable. The digital text scored an overall average of 3.88 on a 5-point scale, ranging from 1 indicating "Strongly Disagree" to 5 indicating "Strongly Agree". The students also positively reported the text was accessible, portable and convenient. Additionally, 100% of students agreed the most helpful feature of the digital textbook was the interactivity, with 75% of respondents citing the immediate feedback provided by the embedded quiz questions. The authors concluded that via the use of an interactive digital textbook, there is a significantly perceivable improvement in student achievement in comparison to students who did not utilize the interactive textbook. This benefit is not without limitation - accessibility to the requisite technology to access the platform presents problems with economic equity and inclusivity.

Liberatore [16] studied the effect of interactive textbook use on student performance and student outcomes in an introductory chemical engineering course. The study was motivated by prior studies, which indicated an overwhelming majority of students (upwards of 80%) do not utilize the assigned texts to complete reading assignments. The author of the study created and implemented an interactive digital textbook, a ZyBook, and evaluated its use in comparison to a traditional book, and how its use correlates to student performance and feelings of engagement. The surveys conducted during the use of the book indicated 46% of students found the book to be interactive, 39% found the book to be concise, while 20% of the students enjoyed the animations and found the text easy to understand and thought it was well organized. Lastly, 16% of the respondents positively viewed the feedback the text provided when an answer was incorrect. Ultimately, 87% of the respondents felt the interactive, online textbook to be useful in the course.

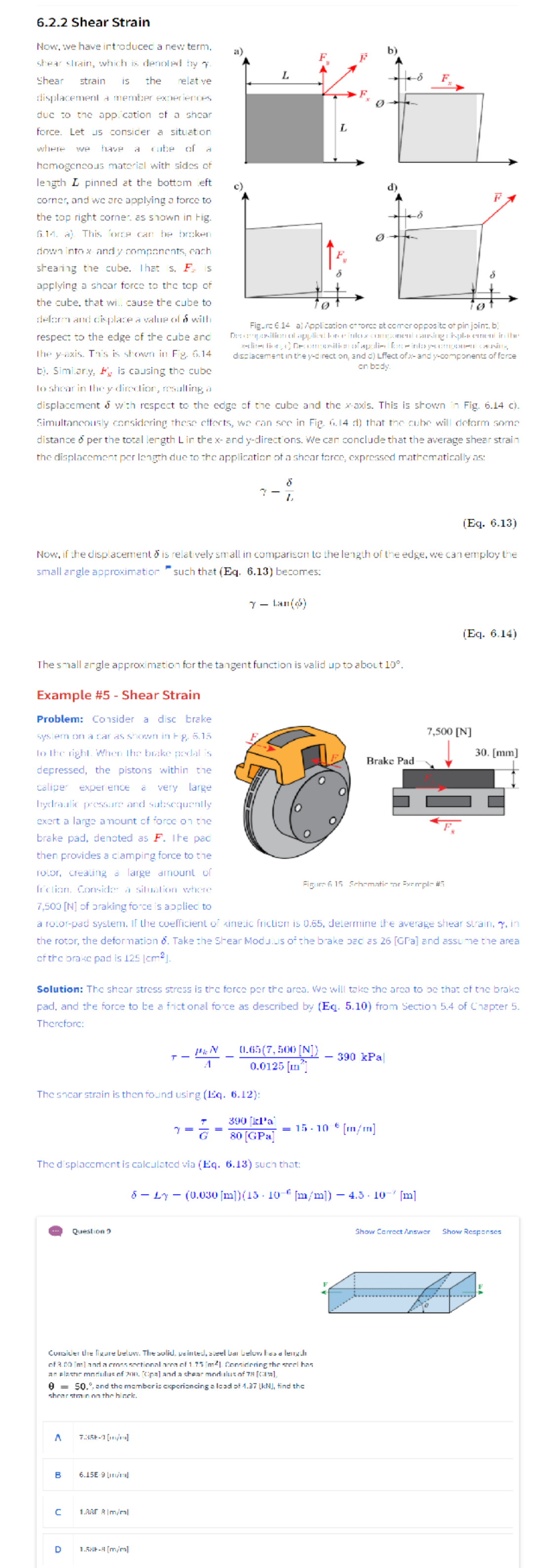
To the authors' knowledge, there are no other comprehensive studies exclusively focused on the use of online, interactive textbooks, and their subsequent efficacy in terms of fostering and augmenting student learning, engagement, and satisfaction. In an effort to understand which components and modes of administration of an interactive, web-based textbook are beneficial to students, the authors developed and implemented a textbook on Top Hat's online platform: *Statics and Mechanics of Materials: An Example-based Approach* [17]. The authors then conducted a mixed-methods study, which was comprised of qualitative and quantitative survey questions, in an effort to assess student engagement with the interactive Top Hat textbook and the impact of the aforementioned textbook on perceptions of understanding of course material. The impetus of this study was not to determine the ability of the text to improve student performance, but rather if students were amenable to its use, and whether they felt the text enhanced their learning experience. A large portion of this study also focuses on the development of the text, which was based on recent pedagogical techniques and advances, and outlines the steps taken to increase interactivity and engagement with the content that is typically not achievable with a traditional textbook. The results of the study provide guidance into the further development, future administration and ultimately the integration of the text into the curriculum.

Interactive Web-Based Textbook

There is non-anecdotal evidence that suggests students are more willing to accept, and read, a textbook that they believe to be useful and easy to access [18]. With this in mind, the approach taken to developing an online, interactive text deviated from that used with traditional textbooks. Many traditional textbooks are written and edited by instructors and content creators with limited input or feedback from the target audience: students. This textbook was co-authored by a student who had recently taken the class. This student was able to draw from their own experiences from taking the course, to better focus the book on student learning and expectations. Being cognizant of these recent experiences, the emphasis of the text was an example-based approach to learning in addition to making the text interactive and engaging. It is noted the student co-author is employed by the University of Pittsburgh Study Lab, a free tutoring service which is offered to all university students. Through the Study Lab, the co-author received certification from the College Reading and Learning Association in peer tutoring and new tutor training. The student co-author was able to incorporate different teaching techniques into the text so as to maximize student comprehension.

Additionally, the authors used CLT when creating the organizational scheme of the text [11]. As a concept was introduced it was accompanied by graphical representations and mathematical formulations. Immediately following the introduction and explanation of the concept, an example along with its solution was presented. The example was presented with all intermediate solution steps, while referencing the preceding concept and mathematics. Following the example, the students were presented with embedded questions, in various forms, to test their qualitative and quantitative comprehension and understanding of the material. An example of this format is shown in Fig. 1. One of the unique aspects of the Top Hat online platform is the text chapters are one continuous page, with hyperlinked sections separating content. As shown in Fig. 1, the student is able to view the conceptual material, example and formative question as one cohesive item, visually reinforcing the concepts associated with CLT. The embedded questions provided immediate feedback on the correctness of the student's answers, allowing them to take inventory of their understanding. At the end of each chapter, students would be presented with review questions, qualitatively assessing comprehension and understanding of the main concepts and themes within the chapter. This compartmentalized, repetition-based learning could be easily augmented for a full-spectrum active-learning environment. For instance, a flipped lecture format could be used as a supplement to the assigned reading, reiterating content through both pre-recorded videos and in-class exercises, providing students two additional exposures to the content. Additionally, think-pair-share exercises could be implemented in Top Hat via additional embedded questions, which the students could work on in pairs or groups, as to provide a final exposure to the content.

Top Hat was chosen as the online platform to create and administer the interactive text for a multitude of reasons. The first was the cost associated with the text. Every student at the University of Pittsburgh had universal access to Top Hat's platform, typically a $90 barrier. The text was comprised of eight chapters, including a total of 66 in-text examples with solutions, 195 embedded, immediate-feedback questions, and 382 homework problems, typically in the form of numeric answer questions. Most of the in-text example solutions were supplemented by MATLAB scripts that were accessible through a course GitHub repository. All of this content came at a cost of $40. The cost of this text was substantially less in comparison to the $146 USD price of the abridged version of the traditional textbook used in the course. Additionally, the Top Hat platform allows instructors to administer online, automatically graded homework without requiring students to purchase an account on a different platform. Platforms such as Sapling Learning can cost up to $70 for a year's worth of course homework access, and Wiley plus can cost $100 for a single semester of online homework access for a singular course. Students are often


6.2.2 Shear Strain

Now, we have introduced a new term, shear strain, which is denoted by γ. Shear strain is the relative displacement a member experiences due to the application of a shear force. Let us consider a situation where we have a cube of a homogeneous material with sides of length L pinned at the bottom left corner, and we are applying a force to the top right corner as shown in Fig. 6.14 a). This force can be broken down into x- and y-components, each shearing the cube. That is, F_x is applying a shear force to the top of the cube, that will cause the cube to deform and displace a value of δ with respect to the edge of the cube and the y-axis. This is shown in Fig. 6.14 b). Similarly, F_y is causing the cube to shear in the y-direction, resulting a displacement δ with respect to the edge of the cube and the x-axis. This is shown in Fig. 6.14 c). Simultaneously considering these effects, we can see in Fig. 6.14 d) that the cube will deform some distance δ per the total length L in the x- and y-directions. We can conclude that the average shear strain the displacement per length due to the application of a shear force, expressed mathematically as:

Figure 6.14 a) Application of force at corner opposite of pin joint, b) Decomposition of applied force into x-component causing displacement in the x-direction, c) Decomposition of applied force into y-component causing displacement in the y-direction, and d) Effect of x- and y-components of force on body.

$$\gamma = \frac{\delta}{L}$$

(Eq. 6.13)

Now, if the displacement δ is relatively small in comparison to the length of the edge, we can employ the small angle approximation such that (Eq. 6.13) becomes:

$$\gamma = \tan(\phi)$$

(Eq. 6.14)

The small angle approximation for the tangent function is valid up to about 10°.

Example #5 - Shear Strain

Problem: Consider a disc brake system on a car as shown in Fig. 6.15 to the right. When the brake pedal is depressed, the pistons within the caliper experience a very large hydraulic pressure and subsequently exert a large amount of force on the brake pad, denoted as F. The pad then provides a clamping force to the rotor, creating a large amount of friction. Consider a situation where 7,500 [N] of braking force is applied to a rotor-pad system. If the coefficient of kinetic friction is 0.65, determine the average shear strain, γ, in the rotor, the deformation δ. Take the Shear Modulus of the brake pad as 26 [GPa] and assume the area of the brake pad is 125 [cm^2].

Figure 6.15 - Schematic for Example #5

Solution: The shear stress stress is the force per the area. We will take the area to be that of the brake pad, and the force to be a frictional force as described by (Eq. 5.10) from Section 5.4 of Chapter 5. Therefore:

$$\tau = \frac{\mu_k N}{A} = \frac{0.65(7,500\,[\text{N}])}{0.0125\,[\text{m}^2]} = 390\ \text{kPa}$$

The shear strain is then found using (Eq. 6.12):

$$\gamma = \frac{\tau}{G} = \frac{390\,[\text{kPa}]}{80\,[\text{GPa}]} = 15 \cdot 10^{-6}\,[\text{m/m}]$$

The displacement is calculated via (Eq. 6.13) such that:

$$\delta = L\gamma = (0.030\,[\text{m}])(15 \cdot 10^{-6}\,[\text{m/m}]) = 4.5 \cdot 10^{-7}\,[\text{m}]$$

Question 9 Show Correct Answer Show Responses

Consider the figure below. The solid, painted, steel bar below has a length of 3.00 [m] and a cross sectional area of 1.75 [m^2]. Considering the steel has an elastic modulus of 200. [Gpa] and a shear modulus of 78 [GPa], θ = 50.°, and the member is experiencing a load of 4.37 [kN], find the shear strain on the block.

A 7.35E-9 [m/m]

B 6.15E-9 [m/m]

C 1.88E-8 [m/m]

D 1.58E-8 [m/m]

Figure 1: Depiction of the text following a concept-example-question format.

required to purchase these platforms in addition to purchasing a book for the course, which becomes prohibitive, and further exacerbates economic inequity [19].

In addition to being more cost effective, the text was easily customizable. Each instructor was able to add supplementary and complementary content within the text in the form of text, equations, images, videos, and embedded questions. Instructors were able to delete content and change the order of content within each chapter via a Word-based text editor and LaTeX-based math editor, and could assign content at any point during the semester as review and/or homework. Content within the text was also able to be hyperlinked to provide a quick path for students to review previous material. External URLs and videos could also be hyperlinked and embedded, respectively. Embedded questions came in a multitude of forms, as shown in Fig. 2. A majority of these question types allowed for up to 25 versions of the same question as to mitigate cheating.

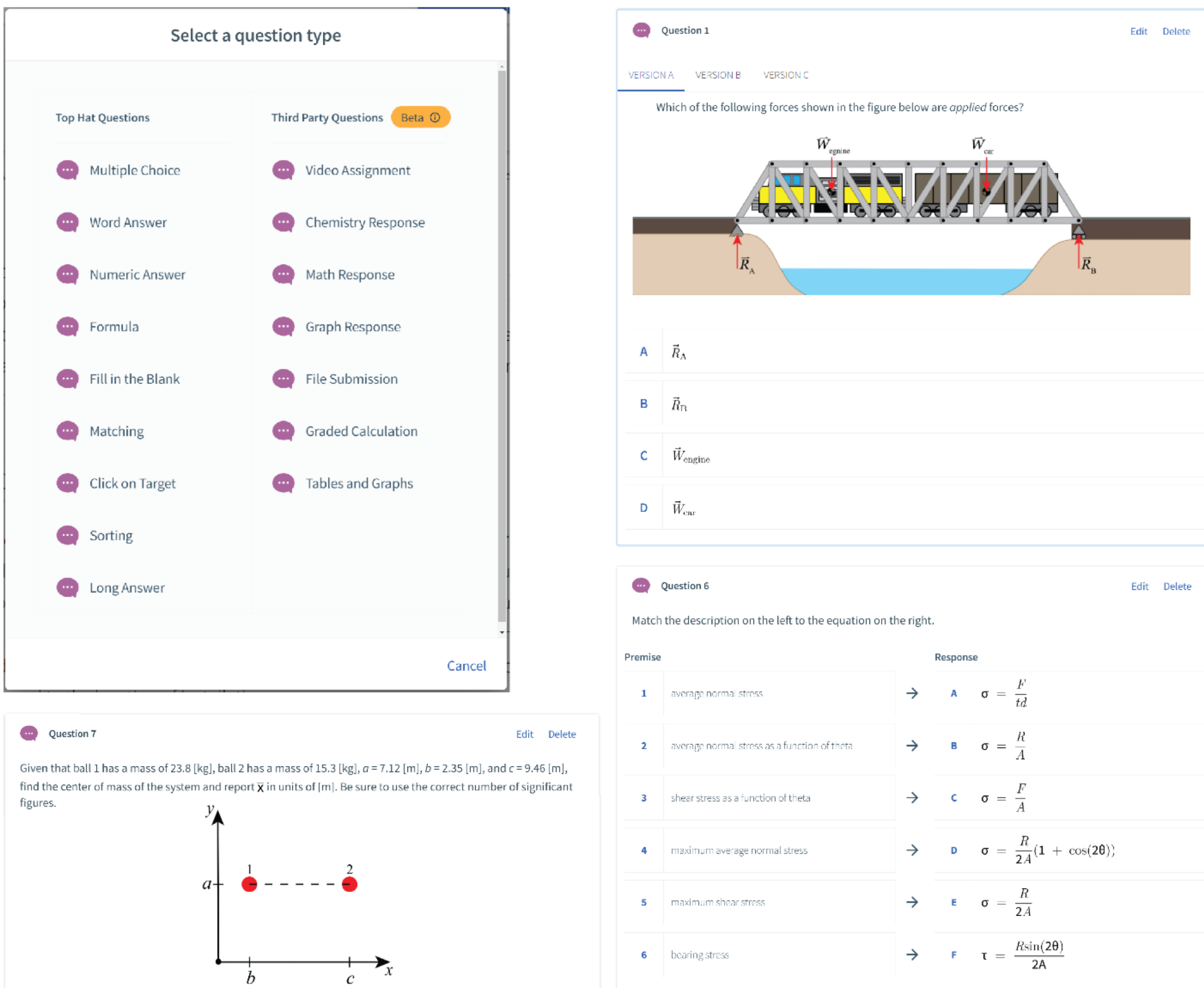


Figure 2: Depiction of Top Hat's embedded question options through the "Select a question type" dialogue box, with Question 1 representing a Multiple Choice with multiple versions, Question 6 representing a Matching, and Question 7 representing a Numeric Answer question.

Top Hat's platform also allowed for the assignment of questions to fulfill a variety of roles during the education process. Various content within the text and course could be assigned via two mechanisms: homework or review, both of which serve important purposes. Assigning content as homework would impose a due date, allow the instructor to specify the number of attempts per question (ranging from one to infinite), whether or not Top Hat would provide instructor-coded feedback to questions answered incorrectly, as well as whether or not to display the correct answer after the last attempted answer. Instructors could also assign a participation grade to questions assigned as homework, in addition to or in lieu of a correctness score, as to track completion and/or provide a participation score, respectively. Top Hat would automatically notify the instructors via email of questions, that were either assigned as review or homework, that had low correctness scores, such that the instructor could take immediate remedial actions. An example of the situation is shown in Fig. 3 below. Students were asked to find the angle between two vectors, considering significant digits. The correct answer is 9.4°. Based upon the large number of incorrect results, the instructor knew which content required remediation. Questions assigned within the reading could then be exported to other assessment methods, such as quizzes and exams, to track student comprehension and competency as they progress through the course.

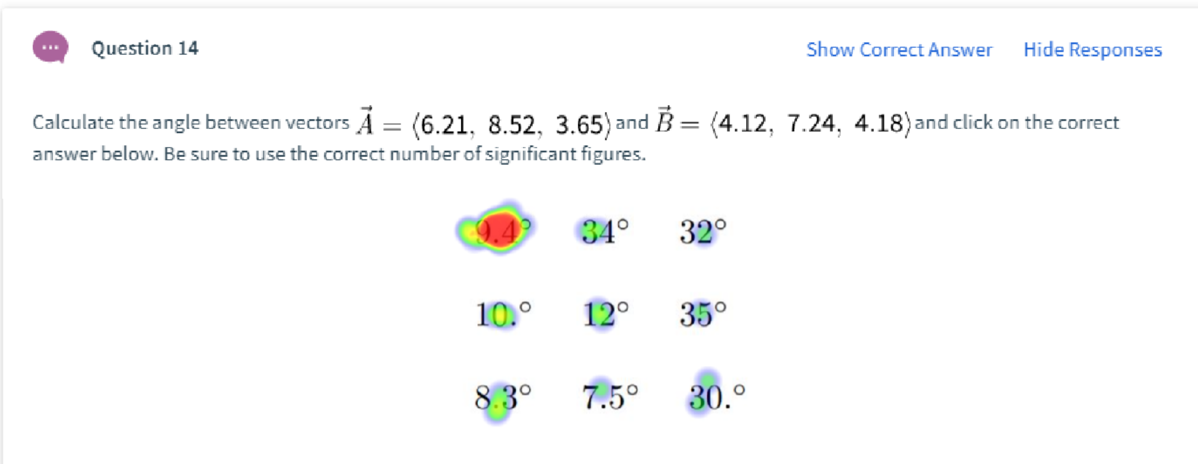


Figure 3: Click on target question with student response shown as a heat map. A higher concentration of red indicates more responses, blue and green fewer responses, and no coloration signifying no responses.

Most question types provided robust options for student answers. For instance, numeric questions allowed for answer tolerancing (either as a percent or specified value), as well as the use of significant figures. Multiple choice questions allowed for the selection of all answers that were applicable. Click on target questions allowed for multiple attempts, and written responses could be interpreted as case sensitive or insensitive. All of the aforementioned questions could also be assigned as review, as shown in Fig. 4. When assigned as review, the students were not graded on completion or correctness of any embedded questions. This assignment method was preferable after the closing of content being assigned as homework, or when student participation was not necessary, for students could practice with the content further and receive immediate feedback without any penalty. In totality, student performance in terms of completion and correctness was easily tracked within Top Hat's Gradebook, which was easily integrated into the University of Pittsburgh Learning Management System.

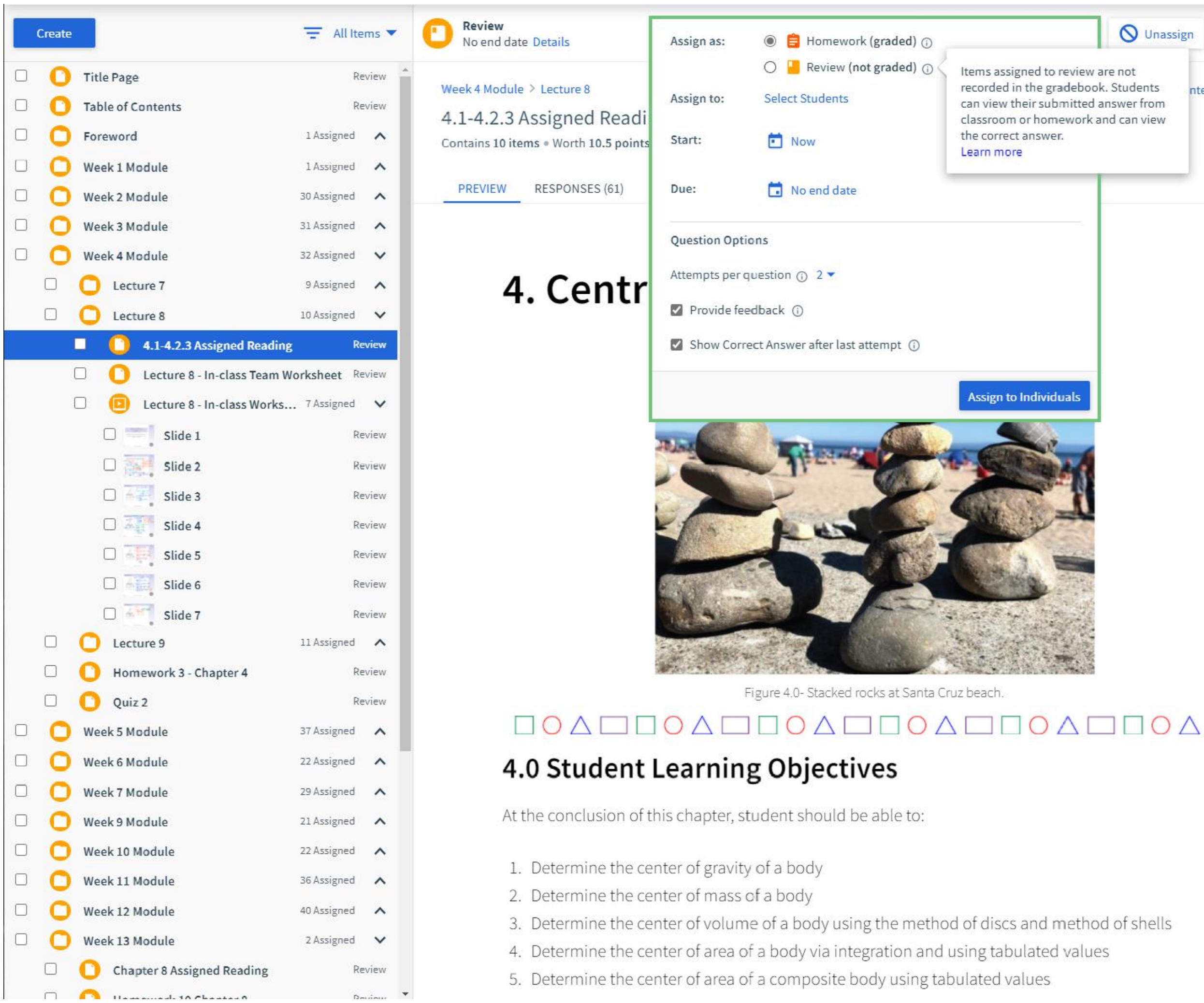


Figure 4: Assignment of course content as either homework or review (green highlight). Depiction of course organization via the course navigation pane. Folders and subfolders are created to organize lectures within weekly modules, e.g., "Week 1 Module", "Week 2 Module", etc. Assigned sections of the text are placed within lecture folders, e.g., "4.1-4.2.3 Assigned Reading" under "Lecture 8". Lecture folders also contain instructor-created slides, as well as additional content such as in-class team worksheets. Within each module, text homework problems and summative assessments can also be assigned, e.g., "Homework 3 – Chapter 4" and "Quiz 2".

Another decisive reasoning for creating the text within Top Hat was that the text was able to be holistically integrated into Top Hat's platform. That is, within the course on Top Hat's website, instructors could include lecture slides, specific sections of the text, homework assignments and summative assessments, all of which could be clearly organized in folders on the navigation bar, as shown in Fig. 4. Using the Top Hat platform, content can be assigned asynchronously and lectures could be presented synchronously to students. The instructor has the ability to annotate pre-uploaded slides, which would immediately be broadcast to the students' devices (smartphone and laptops with no operating system limitation). Synchronous instruction was not limited to presenting lecture material, but was also able to be done with the aforementioned embedded question types during class. Thus, polling could be directly implemented, and think-pair-share activities could be done in coordination with other video conferencing software such as Zoom or Microsoft Teams. Thus, interactivity and engagement could be promoted via incorporation of embedded questions within lectures. Although not the focus of this study, this mechanism allowed for the creation of a cohesive active-learning environment.

Research Methodology

The course in which the Top Hat textbook was used is an introductory Statics and Mechanics of Materials course, which is fairly unique in the fact that students from various disciplines, such as bioengineering, chemical engineering, civil engineering, mechanical engineering, industrial engineering, materials science engineering, and engineering physics are simultaneously enrolled. Based upon the wide breadth of students enrolled in various disciplines and their respective degree plans, there is also a large range of students with various academic standings, ranging from sophomore to seniors. Thus, the text had to be inclusive of and applicable to all disciplines and academic standings, yet be focused enough on mechanical engineering principles and concepts to prepare the mechanical engineering students for their discipline requirements.

The Top Hat textbook was adopted in three sections of the introductory statics and mechanics engineering course in the fall 2020 semester. The three sections had a combined enrollment of 173 students during the assessment period, and were under the instruction of the research team. At the end of the semester, students were asked to complete a survey concerning their experiences with the online text. The survey included no student or demographic identifiers. All three sections used the same syllabus and grading schema, and the engineering topics covered in each of the three sections were identical.

To assign a point value to the pre-class reading, i.e., utilization of the text via the completion of the assigned embedded questions, a participation score of 10% was applied to the course. This score was solely based upon the participation completeness, and not the correctness, of the assigned reading. There was a total of 195 embedded questions within the text. This is aligned with the necessary weight to incentivize student reading [20].

The mixed-methods survey consisted of open-ended questions administered through the University of Pittsburgh approved survey platform, Qualtrics. The students were asked about the impact of the textbook on their understanding of the course material and student engagement with the interactive textbook in comparison to a traditional text. The questionnaire was designed to allow the students to provide quantitative feedback in the form of yes/no, and more engaging/less engaging, while also allowing for qualitative feedback in the form of short answer follow-up questions. The questionnaire that was administered to the three sections is shown in Table 1. Results were analyzed using a coding scheme as proposed by Creswell et al. [21].

Table 1: Top Hat Student Survey Questionnaire

Question	**Answer**
Q1A: Has the use of the Top Hat textbook impacted your understanding of Statics and Mechanics of Materials?	YES/NO
Q1B: If so, how? If not, why?	OPEN RESPONSE
Q2A: Did you find the Top Hat textbook more or less engaging than a traditional engineering textbook?	MORE ENGAGING/LESS ENGAGING
Q2B: Please explain why you found the Top Hat textbook more or less engaging than other traditional engineering textbooks.	OPEN RESPONSE

Results and Discussion

The average response rate to the survey was 61.3% with the lowest response rate for a single question being 59.5%, indicating a high level of student engagement in providing feedback for all aspects of the survey. The survey responses for Q1A and Q2A were analyzed and are shown in Table 2. Over 90% of student responses indicated the Top Hat textbook had an impact on their understanding of the course materials, with 75% finding the interactive textbook more engaging than that of a traditional engineering textbook.

Table 2. Quantitative Analysis of TCG Responses

Q1A: Has the use of the Top Hat textbook impacted your understanding of Statics and Mechanics of Materials?			
Yes:	99	% Responses:	92%
No:	9	% Responses:	8%
Total:	108	% Responses:	100%

Q2A: Did you find the TopHat textbook more or less engaging than a traditional engineering textbook?			
More Engaging:	81	% More Engaging:	75%
Less Engaging:	27	% Less Engaging:	25%
Total:	108	% Total:	100%

To gain further insight into the impact the book had, as well as how it was more or less engaging, each of the quantitative questions were followed by qualitative short answer questions, as previously shown in Q1B and Q2B in Table 1. These open-ended questions were coded based upon the following schemes, as provided in Table 3 and Table 4.

Table 3: Coding Scheme for Q1B

CATEGORY DESCRIPTION	**CODE**
Text was interactive; required engagement through embedded questions in the reading; gave hints	INTERACTIVE
Text was helpful in learning; text was not helpful in learning	HELPFULNESS
Text provided numerous, easily understood, relevant examples; text did not provide sufficient examples to understand material; examples were too difficult or irrelevant	EXAMPLES
Text was well-planned and easy to use, easy to navigate; text was poorly formatted and difficult to use, difficult to navigate	ORGANIZATION
Text contained good explanations and diagrams; concepts and ideas presented were vague or hard to understand	WRITING
Text was difficult to use due to software-based bugs and glitches	SOFTWARE
Text did not provide immediate feedback on homework and worksheets	FEEDBACK

All coding schemes were developed by two analysts after individually reviewing all student responses for each question. The responses for each question were then independently coded by each analyst. The codes were then discussed until a consensus was reached and a 3rd party arbitrated any discrepancies in opinion. The percentage of each code category found in the responses were calculated. All coding schemes followed a general pattern where individual codes could be perceived as mostly positive or mostly negative in terms of student responses. There were also many coding categories consisting of a sizeable number of both positive and negative responses. For Q1B, there were a total of 103 individual student responses out of a combined section size of 173 students, yielding a response rate of approximately 60%. The percentage of each category found in the responses for Q1B are shown in Fig. 5.

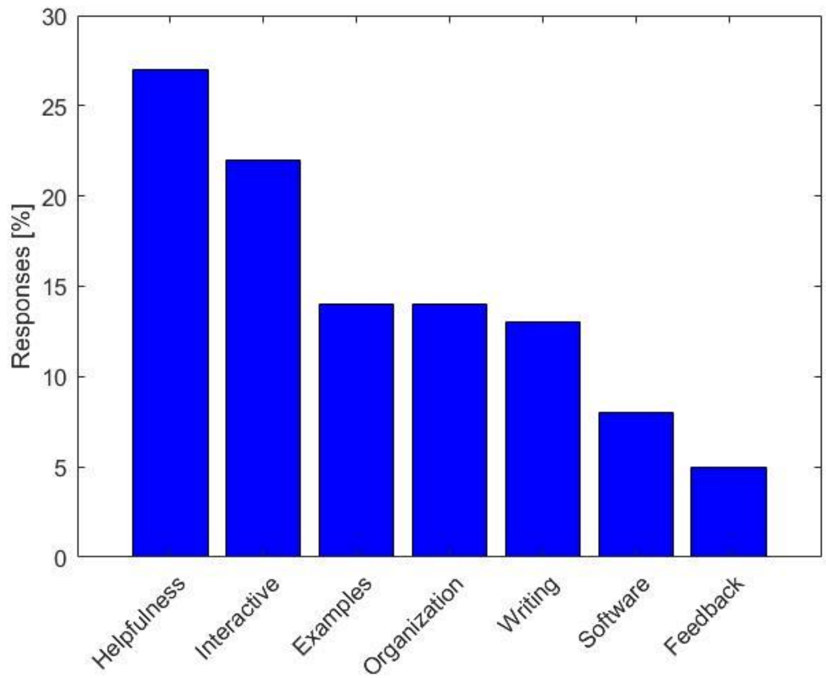


Figure 5: Categories found in n = 103 student responses.

The two largest categories represented in the responses were "Helpfulness" and "Interactive", occurring in 27% (n = 28) and 22% (n = 23) of responses, respectively. There were many interesting responses to Q1B. In terms of the interactive nature of the text, a respondent commented:

> "Feedback during readings is immediate. I like that instead of figuring out later you don't quite understand something."

This indicates that some students found the immediate feedback provided by the embedded questions positively impacted their understanding of the course material. Additionally, 13.6% of responses (n = 14) indicated "Organization" impacted their understanding of the material. One respondent noted, in regards to the text and course:

> "It was something easy to reference as opposed to searching through countless lectures to find one bit of information. I also liked how it had questions in the text, I felt that they kept me on track to understand what I was reading, and prevented me from realizing I hadn't understood anything I'd read."

By integrating the text into the class on Top Hat, the students potentially found the course organization to be beneficial to their understanding of the course material. Students also recognized the compartmentalized approach to introducing material, as was the intention of the organization of the text. One respondent noted:

"It was much more engaging and tested me on bits of information rather than a ton all at once."

While only being present in 5% of responses, the code "Feedback" was an unexpected finding. Traditional engineering textbooks do not provide immediate feedback on homework problems, but some students felt that since the embedded questions provided immediate feedback that all problems in the Top Hat textbook, such as homework and quiz questions, should do so. It is noted that in an effort to mitigate cheating, the instructors decided not to provide immediate correct answer feedback on homework, however, this feature is possible in Top Hat. As noted, many categories had a duality associated with them, as shown in Fig. 6.

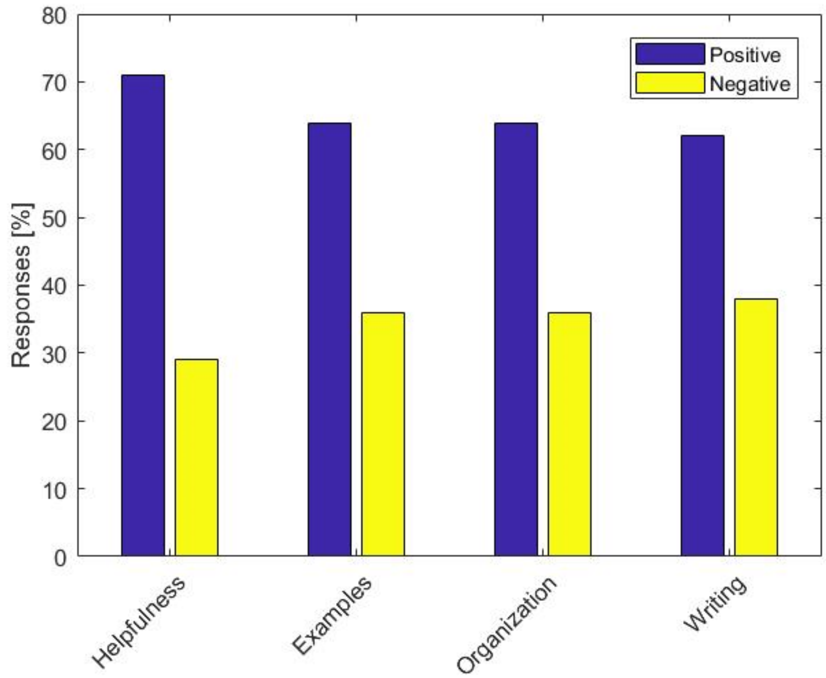


Figure 6: Breakdown of positive and negative responses for different categories.

It can be seen that all mixed-response categories had more positive responses than negative, ranging from a maximum with "Helpfulness" having a ratio of 71% positive to 29% negative, to a minimum with "Writing" having a ratio of 62% positive to 38% negative. The majority of these students felt the text had an overall positive, helpful impact on their understanding of the course, with many noting the content and layout of the book also aided in their ability to understand the material.

Following Q2A, students were able to provide a short answer response, which is designated as Q2B as shown in Table 1. The coding scheme developed to analyze this question is shown below in Table 4.

Table 4: Coding Scheme for Q2B

CATEGORY DESCRIPTION	CODE
Text was interactive; required engagement through embedded questions in the reading; gave hints	INTERACTIVE
Text contained good explanations and diagrams; concepts and ideas presented were vague or hard to understand	WRITING
Text was well-planned and easy to use, easy to navigate; text was poorly formatted and difficult to use, difficult to navigate	ORGANIZATION
Text provided numerous, easily understood, relevant examples; text did not provide sufficient examples to understand material; examples were too difficult or irrelevant	EXAMPLES
Text was helpful in learning; text was not helpful in learning	HELPFULNESS
Students found requiring text for course beneficial	MANDATORY
Students do not enjoy learning or have difficulty learning from textbooks; prefer physical copy	TEXTBOOK
Text was difficult to use due to software-based bugs and glitches	SOFTWARE
Incorrect questions made students not want to use the text; boring	DISCOURAGING
Text did not provide immediate feedback on homework and worksheets	FEEDBACK

There was a total of 105 individual student responses, yielding a response rate of 61%. The percentage of each category found in the responses for Q2B are shown in Fig. 7. The most prominent category found was “Interactive”, being present in 39% (n = 41) of student responses. Students found the interactive features of the text, such as the questions embedded in the readings, to make the text more engaging than a traditional engineering textbook. These findings are on par with previous studies [16]. A respondent commented on the interactive nature of the text:

> “As mentioned, I like the feedback during readings. There's no way to fool yourself into thinking you understand something. When you get a question wrong, you've got to figure it out to proceed.”

Additionally, another student’s comment was aligned with the ideas of CLT. As opposed to a traditional textbook where review and homework problems are typically presented at the end of a chapter, Top Hat allows the instructors to place those questions immediately after the introduction of a concept or example, to fortify learning and understanding. The student stated:

"I enjoyed how Top Hat made it so that I would have to answer questions while doing the reading. This made it so I would have to use the information I had just learned and apply it while it is fresh which lets that information and problem-solving method get processed better."

The students felt other aspects of the text, such as the writing and organization, also promote more engagement with the textbook. The category of "Feedback" showed up again in Q2B with approximately 3% (n = 3) of responses, as shown in Fig. 7. One category that appeared in 4% (n = 4) that was unique was "Discouraging". While few in number, select students noted that due to receiving feedback on in-text problems they answered incorrectly, they wanted to discontinue use of the text. The category "Textbook" was found in this question in a small quantity, but was still of interest. These students disliked their textbook being fully online, and would have preferred a physical copy over an electronic one.

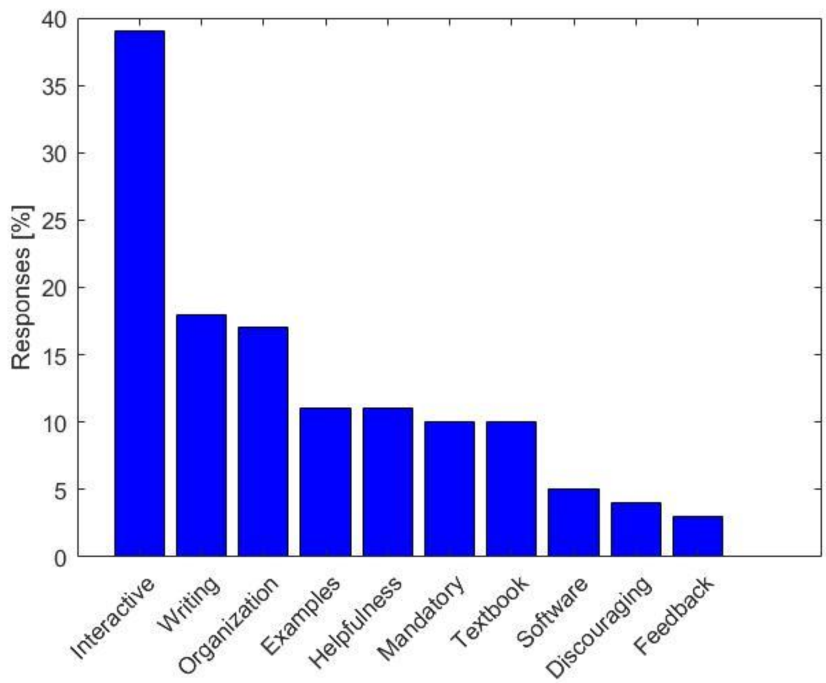


Figure 7: Categories found in n = 105 student responses.

Figure 8 shows the split between positive and negative comments for mixed-response categories within Q2B. Three of the four categories have significantly more positive responses than negative, with "Examples" and "Helpfulness" both having maximum ratios of 83% (n = 10) positive to 17% (n = 2) negative. These students felt the text was engaging due to its overall helpfulness, and in particular because of its layout and worked-out examples. "Writing" was the only category that skewed negative, with a ratio of 37% positive to 63% negative. The students felt the content within the text was poorly written, leading them to feel the online book was less engaging than a traditional engineering textbook. As this was the first edition of the textbook, the authors believe that the writing responses will improve in future editions.

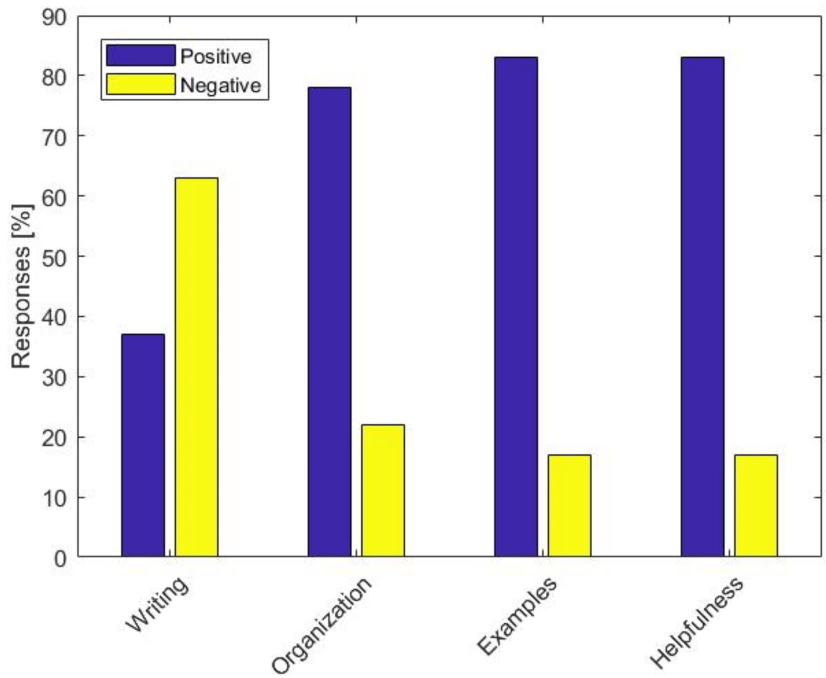


Figure 8. Breakdown of positive and negative responses within certain categories.

Conclusions

The online interactive Top Hat textbook was developed with the goal of improving the educational experience of engineering students enrolled in the course Statics and Mechanics of Materials. The roll-out of the textbook and other learning strategies were successfully carried out in the fall semester of 2020.

Surveys were distributed at the end of the semester to the students who used the interactive text The purpose of the survey was to determine how the students viewed the use of the online textbook. Results showed that 92% of those surveyed found the text to have had an impact on their understanding of the course. The majority of student responses indicated a positive, or beneficial impact, showing that many students found the textbook generally helpful, with an emphasis on interactive features such as the embedded questions being beneficial to learning. Results also showed that 75% of students found the Top Hat textbook to be more engaging than a traditional engineering textbook. Unsurprisingly, students found the interactive nature of the text to be the strongest reason for it being more engaging. Students also found the examples presented in the text and its organization as reasons for the book to be more engaging. It is interesting to note that the organization of the book was designed with CLT in mind, and that some respondents noted the compartmentalized approach to introducing and interacting with material, as well as the multiple exposures to the material, was beneficial to their understanding of course material.

In addition to wanting to know how students felt about using the online textbook for their course, the collected data was also examined for information that could be used to improve subsequent revisions of the text. While the results show that students feel several different aspects of the book could be improved, they especially feel this way towards the written content within in the text. Another issue is the Top Hat software platform itself. Students were unhappy with the number of bugs and glitches encountered when using the online text. Some students felt it both inhibited their understanding of course material and, in some cases, even made the book less engaging than a traditional engineering textbook. A second implementation of the text in conjunction with other teaching strategies will be performed in either the fall of 2021 or spring of 2022. As this will be the second edition of the online interactive Top Hat textbook, the authors will attempt to rectify important concerns as noted by the students.

Finally, based on favorable student responses to this pilot study on the use of an interactive, online Statics and Mechanics of Materials textbook in regards to student perceptions of learning, interactivity and engagement, the following outlines a logical progression of further studies. To ascertain the extent of interactivity and engagement, as well as the impact on student learning and performance, this study will be repeated with a control group, which uses the aforementioned traditional course textbook. The control group will be under the instruction of the researchers, who will also administer a second iteration of the pilot study using an updated version of the Top Hat text on a test cohort. By having a consistent basis of instruction and examination, statistically significant trends can be elucidated. For example, we can gain insight into the efficacy of the textbook by comparing not only student interactivity with embedded questions represented as a percentage, but their correctness scores associated with said questions to student performance on homework, quizzes and exams. Using methods such as ANCOVA, where pre-existing GPA designated as the covariate, will provide further significance to the findings.

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