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Affordable Learning Solutions and Interactive Content in Engineering Mechanics

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Nicolas Ali Libre, PhD, is an assistant teaching professor of Civil Engineering in Missouri University of Science and Technology.He received his B.S. (2001), M.S. (2003) and Ph.D. (2009) in civil engineering with emphasis in structural engineering, all from the University of Tehran, Iran.

His research interests and experience are in the field of computational mechanics, applied mathematics and cement-based composite materials. During his post-doc in the Department of Mathematics at Hong Kong Baptist University (2010-2011) he focused on developing meshfree numerical methods. Given his multidisciplinary background, he was appointed as the director of research in the Construction Materials Institute (2011-2013) at the University of Tehran and assistant professor at Islamic Azad University. In that capacity, he had the opportunity of leading several industry-related research projects and mentoring graduate and undergraduate students.

Over the span of his career, Dr. Libre has authored and co-authored over 17 peer-reviewed journal articles and over 50 conference papers. He has advised and co-advised 7 graduate students and mentored over 20 undergraduate students. He has collaborated with scholars from several countries, including Iran, China, Slovenia, Canada, and the US. He also served as a reviewer for 6 journals and 5 conferences.

Affordable Learning Solutions and Interactive Content in Engineering Mechanics

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Abstract
Digital Affordable Learning Solutions (ALS) provides students with quality yet affordable educational content and enables instructors to utilize multimedia and interactive technology as effective ways of delivering course material. The reduced course content expenses not only allow more students to access the educational material, but also permit the instructors to customize and adapt the material to their teaching style. Incorporation of interactive technology through visually appealing media such as animations, graphics, simulations, videos, and three-dimensional models promotes students' interest in learning theoretical and abstract subjects in science and engineering. In this study, the incorporation of an interactive eBook as an affordable learning solution in Mechanics of Materials is discussed. Features offered in the eBook include responsive three-dimensional models, animations, lecture videos, course summaries, algorithmically generated problem sets, pop-up hints, and guided steps. Such an eBook provides various avenues for students to learn and practice concepts, and has yielded very encouraging results, including increased student performance and positive feedback from the students themselves. The presented interactive eBook has the potential to inspire other educators and course designers to develop and implement interactive tools in their pedagogical approach.

1 - Introduction

Teaching and Learning Materials (TLMs) are essential components of engineering education. TLMs provide teachers with resources to deliver the course content, support student learning, and increase overall student success. TLMs that are offered in various formats such as text, pictures, videos, charts, and slides aid in the learning process by allowing students to explore the knowledge independently as well as providing a resource for practice and repetition. Many college courses, specifically the fundamental and introductory engineering courses such as Chemistry, Physics, Engineering Mechanics, Circuits, and Thermodynamics, rely on the use of textbooks and online platforms that are provided by various external publishers. Despite the high quality of such TLMs, most of those offered by publishers are expensive. It is not unusual for a single textbook to cost more than $200. According the study by Government Accountability Office [1], the price of college textbooks rose 82 percent between 2002 and 2013. Despite a growing online market for discounted books and the popularity of eBooks, the average cost of college textbooks has risen three to four times faster than the rate of inflation over the past 10 years. In a single year, the average college student spends more than $1,200 on books and materials, as reported by the College Board [2]. The survey conducted in this research confirms the high cost of learning resources for engineering students. The main problem is that as the end users, students generally have no role in selecting the course learning materials. The high and rising cost of textbooks and its impending influence on the learning of students who cannot afford such prices has been investigated and discussed by government agencies, researchers, and even public media [1], [3], [4], [5].

Digital Affordable Learning Solutions (ALS) and affordable and open educational resources (AOER) are alternative solutions to traditional TLM [6], [7], [8]. They enable instructors to choose and provide high quality yet affordable TLMs for their students. ALS and AOER (used to refer to the same type of TLM in this paper) are not only used to reduce the cost of textbooks and other required learning materials, but also for enabling the instructors to customize the content and tailor it toward the course objectives and their teaching styles. Digital ALS can take advantage of rapidly growing digital platforms that allow for real-time contribution of various instructors. The input of various instructors who are motivated to produce the best solution possible, along with the peer evaluation process, will often lead to a superior TLM. The entire community benefits from supporting one another and contributing to the development of learning materials that could enhance dissemination of knowledge in a more efficient way.

Another advantage of Digital ALS over TLMs is the utilization of multimedia and interactive technology to effectively deliver course material. Most publishers offer textbooks in both printed and digital format, but the eBook typically contains the same content as the printed version, just adapted to be displayed on digital devices. However, a book that is designed for print and then adapted to be displayed digitally cannot utilize the full power of digital media, such as multimedia embedment, responsive content, and interactive engagement. Utilizing the capabilities of digital media enables authors and instructors to convey the subject matter in a more efficient way and provides students with various avenues of learning. Several researchers [9],[10],[11] have shown the influence of visualization on the effectiveness of engineering education and how the lack of visualization capabilities among engineering students can prevent effective knowledge transfer. The eBooks that are designed for print include the figures in a two-dimensional format even if the object was modeled in three dimensions. However, many digital devices that are currently available are powerful enough to render even complicated three-dimensional models and provide students with a real time interaction with CAD models. Content visualization is able to convey the subject matter in a condensed manner, increasing its assimilation compared to traditional text transmission [9].

In this study, an affordable learning solution in the form of an interactive eBook is developed and its incorporation into an entry level engineering course as an affordable learning solution is discussed. By choosing ALS over traditional learning materials, more students can acquire the course materials they need to succeed and benefit from their learning experience at a reduced cost.

2 - Development and application of digital ALS in Mechanics of Materials

The digital ALS that is developed for Mechanics of Materials is in the form of interactive eBook. This learning resource is intended to provide students with the fundamental concepts and applications of Mechanics of Materials. The developed TLMs place a great emphasis on examples, solving problems, and practical algorithms for solving problems that engineers are faced with in designing various elements. The illustrations, models, and steps used in the solved problems are designed to explain and depict the technical components graphically in a way that augments learning specifically for visual learners. Other illustrations, three-dimensional models, and animations help students visualize the components of problems. The features offered in this ALS include:

Dynamic, responsive content designed for digital devices: An interactive eBook has so many more capabilities than a printed textbook. One benefit is the ability to embed various forms of media to create a dynamic and responsive environment. In the developed eBook, students can have instant access to video segments or voice recordings on different topics. Students can use the media to review topics and lessons to enhance their learning. The digital ALS allows students to access the material from anywhere using their electronic device of choice instead of carrying around a large textbook. The ALS displays dynamic and responsive content that gives students a more in-depth, virtual experience beyond the limits of ink and paper. The ALS also provides multiple avenues for the different styles of learning. The lesson notes and animations benefit the visuals learners, the example problems benefits the reading/writing learners, the interactive models benefit the kinesthetic learners, and the embedded media lessons benefit the auditory learners.

Real time interactive 3D models: Because visualization is sometimes a challenge for students, the real time interactive three-dimensional models are an excellent source of learning. Interactive 3D models are already available on many lessons and examples, and will continue to be developed and spread to more. Using these models, students are able to visualize components and structures as if they are holding it in their very own hands, and with much more freedom than ever found in a paper textbook. Students can rotate the model fluidly to see every degree of the 3D model. Two views of a sample 3D model are shown in Figure 1.

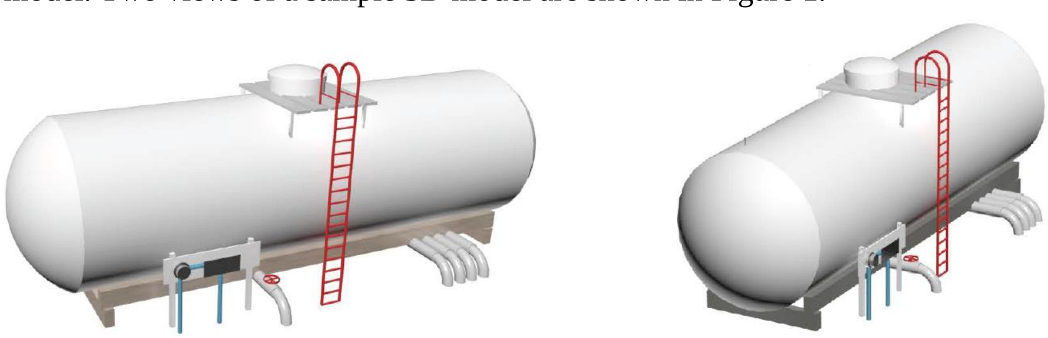

Figure 1: Sample three-dimensional model

Animation: In addition to the interactive models, the three-dimensional animated models allow students to visualize the effects of forces, torques, etc. on the structures used in an example problem. The animation provides a short video clip for students to watch, replay, and pause while the clip describes the different steps of the problem. It has been found that animations are very useful for students when solving complex problems that involve several steps. Instead of students having to imagine how the complex problem looks and reacts in their head, they can directly observe and learn from an animation. For example, a combined loading problem involves three-dimensional analysis. Three-dimensional animations are very useful for students to visualize how each force affects the beam in three dimensions. Students can use this tool to help them visualize an example as if they were watching the forces being applied in a laboratory, as well as better understand the reactions, steps, and concepts in additional examples. Sample frames of an animation are shown in Figure 2.

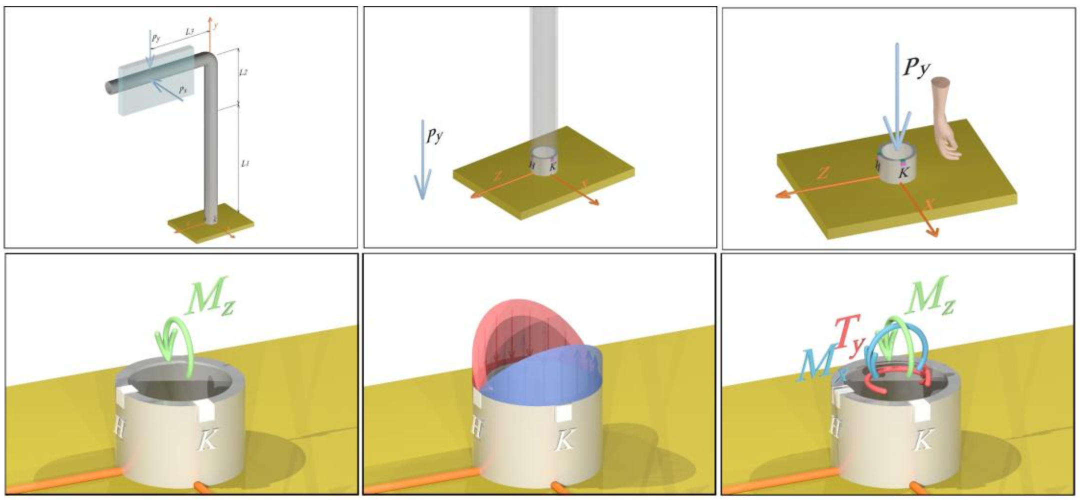

Figure 2: Sample frames of an embedded animation

Responsive hints and guided steps: There are several examples in the eBook that students can use to learn, practice, and assess their knowledge. There are many different options for how a student can practice examples. A student can simply view the problem statement, work it out on their own, and then compare their steps and solution to the book. If they get stuck, they can receive a responsive hint for a small part of the problem (see Figure 3) or they can use a guided step-by-step solution for the whole problem (see Figure 4). The guided step-by-step option allows students to follow along with a worked out solution for the example they are solving. The responsive hints and guided step-by-steps allow the example problem section of the book to be adaptive to every students' level of knowledge on the material.

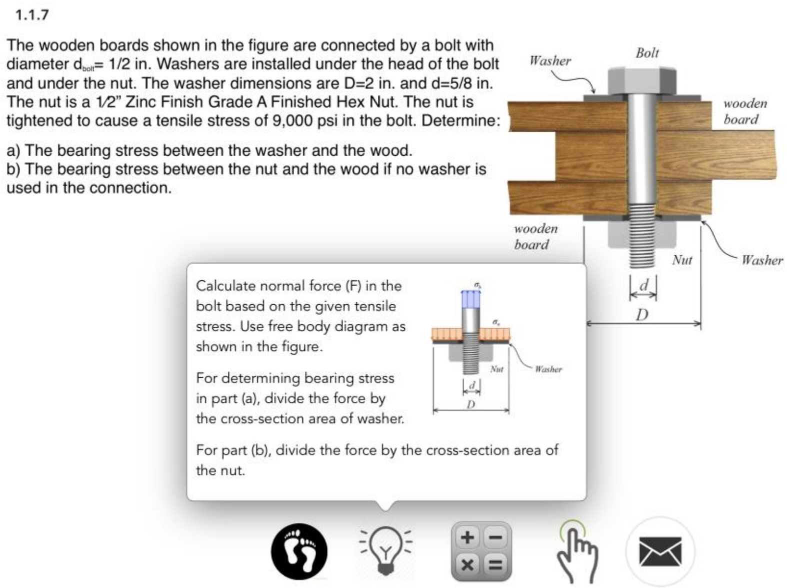

Figure 3: Sample responsive hint

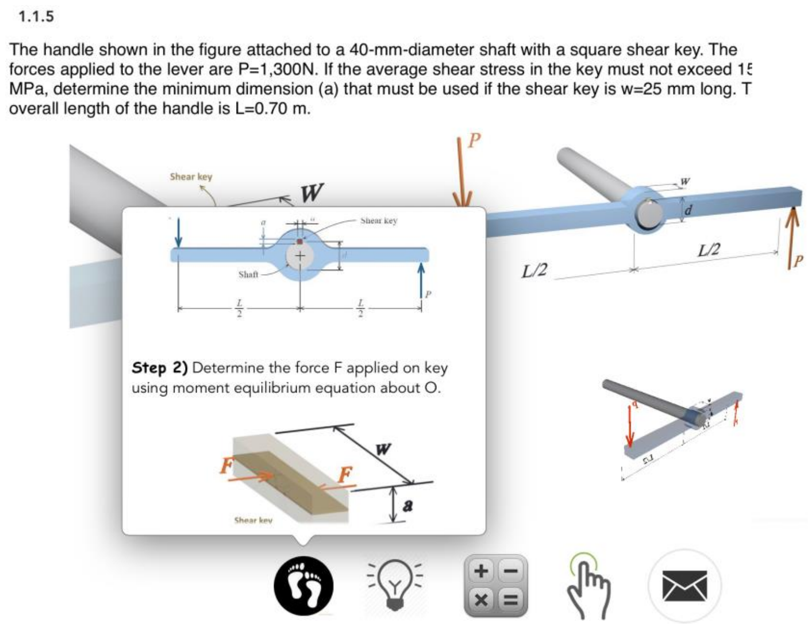

Figure 4: Sample guided step-by-step

Algorithmically generated problem sets: Plenty of algorithmically generated problem sets are available to students; these generate the problem with random numbers every time the problem is attempted. A unique feature of the problems is that students can repeat a problem over again with new randomly generated parameters without fear of losing any points towards their grade. This allows for better learning through repetition.

Automatically graded assessment materials: In addition to the ALS textbook, students also use a website for homework and practice problems. A key benefit of the website is that it automatically grades assessment materials. This is beneficial to both students and instructors; students receive feedback while they attempt the homework and do not have to wait to see if their problem-solving method is correct, while instructors can obtain feedback from every student immediately without having to grade the submission. It also provides instructors with instantaneous student performance analytics while students work on the assignments. It allows instructors to detect possible issues and take proactive measures to resolve the issue.

These unique features help create a custom learning experience for students with various learning styles. Each chapter begins with a course summary that provides main concepts, equations, formulas, key points, step-by-step tutorials, and algorithms associated with the topics discussed in that section. Lecture videos are also provided for select sections. Numerous walk-through examples are presented in each chapter that can be used to reinforce students' learning.

3 - Results and discussion

The eBook has been utilized in three consecutive semesters as a supplementary ALS in Mechanics of Materials, a course offered at Missouri S&T. Missouri S&T is one of four colleges in the University of Missouri system. In total, there are 76,000 students in the system; Missouri S&T is the campus with the most emphasis on science and engineering. There are about 9000 students studying at this campus, 77% of which are pursuing undergraduate degrees, with most of them majoring in engineering.

Mechanics of Materials is a core introductory course for many engineering disciplines, including civil, mechanical, aerospace, architectural, and metallurgical engineering. This course is also a part of programs such as environmental, manufacturing, nuclear, engineering management, and petroleum engineering. The course is offered in large sections, each typically having more than 100 students. In total, there were about 200 to 350 students in this class in the semesters that were studied. The cost of the online homework platform and the textbook before adopting the ALS in this course was about $80 to $220 depending on the various options offered by the publisher (i.e. eBook, paperback, hardcover, and etc.). The price has reduced to 0 to $50 after switching to the ALS. All mandatory learning materials such as the online homework platform, the pre-class video assignment, and in-class polling system were provided for students at no cost. The full edition of the eBook was optional ($50). There were also 20 iPads loaded with the eBook that students could freely borrow for studying.

During the research period, academic performance was compared to determine the learning impact on students when the ALS were incorporated into the course. Students' understanding of the subject matter was assessed by weekly assignments and four midterm exams throughout the semester. The final examination was conducted at the end of semester (week 16). The final exam questions were pulled from a database of standard questions with randomly generated numbers that were used several times before the research period. To prevent students from passing on exams from one year to the next, students were not allowed to keep their final exams. The performance of students in the final exam before the research period is considered as the reference; performance of students during the research period was compared with the reference to evaluate impact of ALS on students.

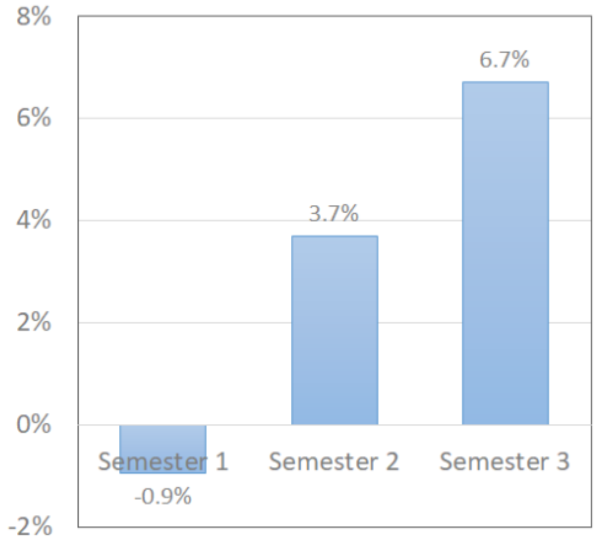

Figure 5: Academic performance of students after adopting ALS relative to reference

Figure 5 shows the performance of students in the final exam during the research period compared to the reference baseline. A grading scale of 0 to 100 was used for the exams. The class average performance in the first semester after adoption of the -0.9% lower compared to the reference semester. The difference is less than 1% which shows there is not a significant difference between the test group and reference group in the first semester of switching to the ALS. In the second and third semester, the relative academic performance has improved by 3.7% and 6.7%, respectively. It should be noted that the adoption of ALS was not the only difference between the test and the reference semesters. Some other learning modules such as active learning and problem-based learning were incorporated. It is not possible to separate the effect of each module on students' learning and determine the pure effect of adopting ALS, however, the results of this study clearly reveal the possibility of substituting commercially available textbooks and online platforms with more affordable learning solutions without sacrificing the teaching quality. The transition from commercial platforms to open educational resources was smooth and overall student performance has improved over time.

A survey was performed to evaluate the average cost of mandatory TLMs as well as understand the students' familiarity with and preference of traditional versus affordable learning resources. The survey sample size was n=101 students. The sampled students were majoring in different engineering disciplines and were at the sophomore, junior and senior levels. It was found that an average student spends about $586 per year for textbooks and other educational resources. The histogram graph of students' responses are shown in Figure 6. Other main findings of the survey are summarized below:

- 41 percent of students have off-campus jobs to pay for their studying expenses
- 33 percent said they didn't register for a course or took fewer courses due to the cost

- 16 percent dropped a course or failed in a course due to the high prices of educational resources
- 38 percent had to save money for textbooks and other educational resources by reducing their vital expenses such as food
- 99 percent of students think the educational institute should have strategies to provide students with affordable educational materials

Some students mentioned that they avoid taking courses that require expensive textbooks or homework platforms because they cannot afford it. Many said that they try to find alternative online resources or older editions of the required textbooks whenever possible even if it is detrimental to their grades. The results of this survey confirm the previous studies on the impact of studying expenses on students' learning, and is a motivation to develop, adopt, and use affordable learning materials.

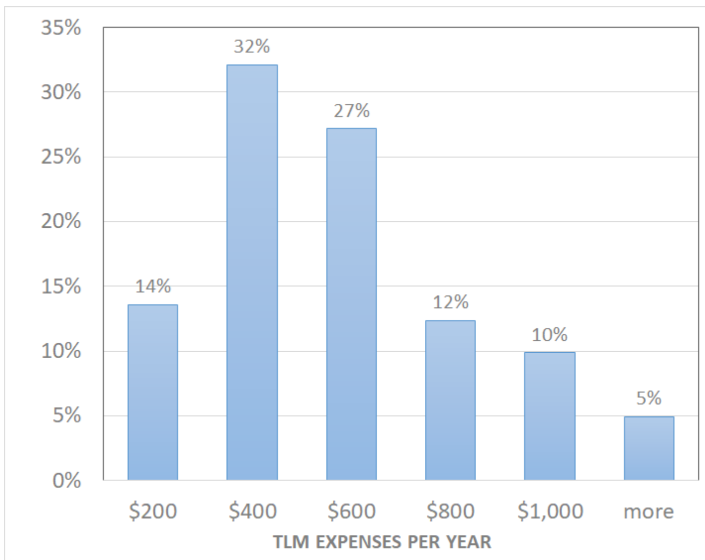

Figure 6: Expenses of Teaching and Learning Materials per student per year

4 - Concluding remarks

The results of this study show the possibility of adopting open educational resources and affordable learning solutions as affordable yet quality learning materials in engineering education. The survey performed in this study along with the literature review shows the impact of the high cost of educational resources on students' learning. Development, adoption, and implementation of open educational resources could be a viable solution not only for reducing costs but also for enhancing student learning. Digital ALS can take advantage of electronic devices and provide students with learning materials that are not possible via traditional TLMs. Following the successful application of the ALS developed in this course, it will be made available to other instructors in the future.

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