An Open Educational Resource Engineering Capstone Design Textbook with Case Studies Relevant to Student Experience

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In Spring 2020, the Mechanical & Aerospace Engineering (MAE) Department at the University of Florida (UF) added a mandatory second semester to its existing one-semester capstone design program. Previously an elective, the newly required second course challenges students to build functional prototypes of designs created on-paper in the sequence's first semester. Given MAE's enrollment of over 1,800 mechanical engineering undergraduates, more than 175 seniors (among the largest such cohorts in the country) must be shepherded through the capstone program each semester. A new and novel set of instructional and course administration techniques largely borrowed from industry was implemented to manage this large-enrollment realization phase of the UF MAE Capstone program. One component of this new approach is joint authorship and course adoption of a new Open Educational Resource (OER) engineering capstone design textbook, a free and accessible resource that students may retain as they transition into professional practice. An important attribute of the OER text is emphasis on engineering design case studies borrowed from real capstone projects as opposed to examples taken from industry. This emphasis, unique among engineering design texts, is intended to improve the content's intellectual accessibility for students by framing design problems in contexts relevant to their experience. This paper chronicles how a diverse team including UF faculty, librarians, academic administrators, instructional designers, and academic publishers are collaborating to produce this OER engineering design text.

Keywords: Open Educational Resource (OER), Capstone Design Textbook, UF-MAE Way, Case Study Relevance

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Introduction

Like many capstone engineering design programs, the Mechanical & Aerospace Engineering (MAE) Department at the University of Florida (UF) has no standard adopted capstone course textbook, and faculty curate course materials from a variety of sources as well as develop their own. There is need for a new and unified design text for mechanical engineering to address lack of one focused on capstone.

In 2020 Spring, UF's MAE Department added a mandatory second semester to its existing one-semester capstone design program. Previously an elective, the newly required second course challenges students to build functional prototypes of designs created on-paper in the sequence's first semester. Given MAE's enrollment of over 1,800 mechanical engineering undergraduates, more than 175 seniors per semester (among the largest such cohorts in the country) must be shepherded through the capstone program. A new and novel set of instructional and course administration techniques largely borrowed from industy was implemented to manage this large-enrollment realization phase of the UF MAE Capstone program, including creation of a much-needed capstone design textbook. Capstone often includes a lab-based realization build stage, usually requiring students to pay laboratory fees. To minimize cost for better student course accessibility, it is desirable to publish the needed new textbook as an Open Educational Resource (OER). It is anticipated that over 380 UF mechanical engineering undergraduates per year will use this OER design textbook in capstone, and the potential national user base is over 30,000 mechanical engineering seniors per year [i].

According to ABET, there are 327 mechanical engineering and 96 general engineering programs active globally and accredited [ii]. Each program has a capstone (or equivalent) design course in its curriculum to meet and maintain accreditation requirements. Each of these courses is a potential OER design textbook adopter. While conventional copyrighted design textbooks are available, no widely accepted standard exists specifically for mechanical engineering capstone design. Given this universal need, the potential textbook user base is at least

423 courses per year Assuming a conservative 10% market penetration replacing a $75 copyrighted design text with an OER alternative, the annual global cost savings to students will exceed $225,000.

Background

A nationwide US survey focused on engineering capstone practices and trends has been administered about every ten years; first by Todd et al in 1994 [iii], then by Howe in 2005 [iv], and most recently in 2015 by Howe and Goldberg [v]. The 2015 survey received 449 responses, and in 2015 there were 2542 ABET-accredited programs with the term "engineer" or "engineering" in the title [vi]. ABET General Criterion 5 stated: "Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints" [vii]. We infer that to be accredited all 2542 listed programs had some type of capstone program in 2015 when the Howe and Goldberg survey circulated. The survey directly probed 17.7% of all ABET accredited capstone programs in 2015, making it the most comprehensive resource available from which to draw conclusions about capstone program trends, features, and emerging practices.

From this purview, the most comprehensive available view of engineering capstone, Howe and Goldberg do not recommend using a textbook to teach the course. They state that since techniques and tools of design are constantly in flux, to keep up with advancements implemented in industry it is recommend to use industry trade publications to source course material and to invite guest speakers to class knowledgeable about current trends in design practice [iv]. A unique feature differentiating OER publishing from conventional copyright is ability of textbook authors crowdsource contributions. Instead of revising a text every few years to follow emerging trends, a community of OER textbook adopters can maintain the book continuously, making the OER option much more like the periodical trade publications recommended for use in capstone by Howe and Goldberg than conventional textbooks.

Certainly, there are conventional engineering design textbooks in-print that could be adopted, but they are expensive, forcing students to make undesirable trade-offs. For example, a study by Morning Consult for educational technology and services company Cengage asked 1,651 current and former college students how textbooks purchasing impacts their finances. Forty-one percent said textbooks had "somewhat of an impact" on their financial situation, and forty-six percent said textbook purchasing had "a big impact. [viii]

So, before starting this project, a comprehensive search was performed to identify existing OER engineering design textbooks to consider for course adoption. Khandani published a short booklet intended for use in introductory engineering design courses that is publicly available to download, but with copyright retained by the author [ix]. While booklet covers the basic engineering design approach and can be a useful resource, it does not cover the topic comprehensively as would a textbook. Similarly, Ullman provides freely available engineering design educational resources freely accessible from his Web site [x]. However, these materials are linked to Ullman's engineering design textbook, published under conventional copyright [xi]. The utility of Ullman's Web materials is limited without the complementary textbook. Finally, an out-of-print edition of Cross's mechanical engineering design textbook [xii] is available for free download from several Web sites. However, a personal communication with the publisher indicated that public release of this textbook was not intended, and use of copies downloaded freely from online sites constitutes copyright infringement. In short, the sought OER mechanical engineering design textbook for capstone does not exist, which motivates the project here described to develop one.

Methods – Textbook Structure

While the OER engineering design textbook we are producing addresses a large and unmet need for technical instruction, the text is also unique in its structure and contents, providing capstone-specific instructional support for faculty not found in existing design books. The book is divided into three parts organized specifically to support university classroom instruction of engineering design. Part One breaks the engineering design process into its constituent components and devotes a chapter to the mechanics and execution of each component. As different schools use variations on the design process sequence, the text is broad and comprehensive in its presentation, and it invites instructors to adopt the subset of design process components they need to suit their projects and school cultures. A faculty member adopting the book can refer to Part One as a suggested schedule outline for course instruction.

Part Two of our textbook capitalizes on the individual specializations of the co-authors to show the interdisciplinarity of design with other mechanical engineering specialization areas. Each author is writing a chapter describing how design melds with their specific discipline and how their subject area informs design. This task will be structured around "reverse engineering analyses" of common and inexpensive objects including an RC car shock absorber and a disposable medical syringe. Instructors adopting our OER design text will

rely on Part Two to showcase how engineers from various mechanical engineering specializations address and solve design problems.

Part Three contains numerous case studies showcasing recent capstone design-and-build projects undertaken by engineering design faculty co-authors. Like the rest of the book, our approach to case studies is unique. Existing engineering design texts that use case studies select examples from industry and professional practice. While interesting, conventional design texts' focus on industrial examples renders these case studies inaccessible and nonintuitive for students. While students can think in the abstract about design problems faced in industry, these problems rarely align with students' personal experiences in university classrooms and labs and therefore detract from or confound engineering design instruction. Industry-focused problems found in many engineering design books – how to produce thousands of identical units or build massively complex systems like airplanes – are less relevant to students than university project-based examples like building a functional prototype for a start-up company. Our approach describes actual past projects undertaken in UF MAE capstone courses to make these example real for students.

Methods – Textbook Development Team

The textbook development team spans five units at UF and includes three other geographically distributed partner colleges located in different regions of the country. The emphasis in selection of internal UF partners was bridging subject expertise and functional skills in instructional design, project management, rights evaluation, and publishing. Partner colleges outside UF were selected for each school's unique geographic location, enrollment size, public vs. private status, research vs. teaching focus, and whether schools are primarily minority-serving (e.g., HBCU's). Each partner institution brings a unique perspective into the project, which we expect to accelerate adoption of the OER design textbook by a variety of schools and programs.

This approach supports not only the development and dissemination of the OER design textbook, but also its long-term sustainability. Beyond its value to engineering students, this project will act as a key pilot case for collaborative OER textbook development at UF. This process will facilitate refinement of roles and responsibilities and will help demonstrate the value of OER in promoting student success.

Methods – Adoption, Funding & Dissemination

Faculty consortium members have committed to adopting the OER engineering textbook for their courses when teaching capstone at their home universities. The textbook will be further advertised and disseminated by a national publicity campaign centered on the 2022 Capstone Design Conference.

Funding from UF to support this OER textbook development project will be leveraged by the consortium to compete for additional funding from external federal, professional organization, and foundation sources that support ongoing textbook development. We will also seek funding and in-kind support from large open source textbook clearing houses like LibreText and OpenStax. For example, we will apply to the OpenStax OER Institutional Partnership Program, which offers an annual competitive grant for in-kind OER resource development valued at $20K.

Results – Textbook Content

The OER design textbook's preliminary table of contents is as follows:

Part One: The Engineering Design Process
1. Identifying Problems & Customer Needs
2. Researching the Problem
3. Quantifying Metrics
4. Identify Functions and Subsystems
5. Concept Design Phase
   a. Brainstorming
   b. Divergent Ideation
   c. Mixing and matching ideas
6. Qualitative Concept Down-Selection
7. Concept Design Review
8. Quantitative Down-Selection for Prototyping
9. Preliminary Design
   a. Simulations
   b. Mockups
   c. Proof-of-Concept
   d. Functional Prototypes
10. Preliminary Design Review
11. Detail Design
   a. Presentation Prototyping
12. Final Design Review/Approval
13. Product Documentation
   a. Detail Drawings
   b. Bill Of Materials (Standard Parts and Fabricated Parts)
   c. Product Specifications
14. Pilot Production
15. Product Testing
16. Full-Scale Manufacturing

Part Two: Tying Design to Engineering Specializations
1. Energy and thermal science considerations in design
2. Tolerancing, fabrication, and manufacturing considerations in design
3. Vibrations, dynamics, and stability in design
4. Material mechanics and material science in design

5. System dynamics, controls, and numerical analysis in design

Part Three: Engineering Capstone Case Studies
1. Research project type case studies
   a. Solar concentrating parabolic tough refit to evaluate heat collection element vacuum integrity
   b. Blower door and thermal camera for accessible building energy audit kit
2. Internal product development case studies
   a. Espresso machine
   b. Autonomous hydro-foiling wetlands survey craft
   c. Automated Precipitation Sampler for Marine Science Research
3. External product development case studies
   a. Tesla turbine for biomass-to-energy start-up company
   b. Wildfire suppression drone system to drop fire-extinguishing balls
   c. Hydraulic jump interrogator lab kit for remote online learners for education technology company
4. Engineering student competition case studies
   a. Formula SAE competition car hydraulic brakes
   b. IREC Rocket Competition altimeter-controlled air brake

Discussion & Conclusion

While inexpensive options exist for students to "rent" engineering design textbooks, these options are not free like OER, and they strip students' access to critical textbook content once the rental ends. By contrast, an OER engineering design text offers permanent, free access for students, which continues when they become newly graduated students and start careers as practicing engineers.

The set of instructional and course management techniques implemented to manage this new large-enrollment MAE capstone realization phase is called the UF-MAE Way. One component of this new approach is authorship and adoption of a new OER engineering capstone design textbook. This OER text is free and accessible to all, which simultaneously improves course materials access for students and allows them to retain access to these critical materials as they transition into professional engineering practice. Another attribute of the OER text is emphasis on engineering design case studies borrowed from real capstone projects as opposed to examples taken from industry. This emphasis, unique among engineering design texts, improves content intellectual accessibility for students by framing design problems in contexts relevant to their experience. This paper chronicles how a diverse team including UF faculty, librarians, academic administrators, instructional designers, and academic publishers are collaborating to produce this OER engineering design text. This work showcases how UF is leveraging the cooperative expertise of faculty and staff toward production of an OER textbook, demonstrating a successful organizational model for publishing much-needed OER engineering textbooks.

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