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Author

Dr. John R. Haughery
Asst. Prof. of Automation and Electronics Technologies in the Dept. of Applied Engineering, Safety and Technology at Millersville Univ. of PA and Affiliate Asst. Prof. in the Dept. of Agricultural and Biosystems Engineering at Iowa State Univ.

Mr. Oyetunji S. Olaniba
Industrial and Agricultural Technology Ph.D. Student, Teaching and Research Assistant of the Dept. of Agricultural and Biosystems, Iowa State Univ.

Abbey K. Elder
Open Access and Scholarly Communication Librarian, Iowa State Univ.

ATMAE
701 Exposition Place
Suite 206
Raleigh, NC 27615

www. atmae.org

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The Effectiveness of Open Educational Resources to Improve Access and Learning in an Electricity Course

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The Effectiveness of Open Educational Resources to Improve Access and Learning in an Electricity Course

Dr. John R. Haughery is an assistant professor of Automation and Electronics Technologies in the Department of Applied Engineering, Safety and Technology at Millersville University of Pennsylvania and affiliate assistant professor in the Department of Agricultural and Biosystems Engineering at Iowa State University. His 15+ years of teaching, research, and practice are focused in the areas of robotics, automation, controls, human-machine interactions, electric power/energy systems, and engineering/technology education. Dr. Haughery is a Certified Senior Controls Engineer (CSCE), Controls Exam Commissioner for the ATMAE Board of Certification, Vice-President for the ATMAE Student Division, past Vice-President for the ATMAE Electricity, Electronics, Computer Technology & Energy Issues (EECT) Division, and past member of the ATMAE Board of Accreditation, as well as a recipient of the Exemplary Service and Contributions to the Board of Accreditation award from ATMAE, and the Central Keystone Section's 2006 George Espy Achievement Award (ISA). Dr. Haughery received his BS in Industrial Technology: Electronic/Control Systems from Millersville University of Pennsylvania (2006), MS in Engineering and Technology Management from Morehead State University, KY (2014) and a PhD in Industrial and Agricultural Technology from Iowa State University, IA (2017).

ABSTRACT

A primary motivation for using Open Educational Resources (OERs) is to increase access by reducing students' financial burden. While this was a motivating factor in this study, the authors also were interested in understanding OER's impact on student learning. Therefore, this study describes the adaption process for an OER textbook used in a junior-level undergraduate electricity course and evaluates this OER's effectiveness to increase student access and improve learning over the baseline textbook. A quasi-experimental, non-equivalent design collected exam scores, and self-reported survey responses from n=144 students in a comparison (non-adapted OER; n=83) and treatment (adapted OER; n=61) group was used. Based on Student's t, Kolmogorov Smirnov, and Chi-square ($\chi 2$) tests, the adapted OER was effective at improving access and learning while also saving enrolled students an average of $8,000 per year, collectively. A brief background of OER databases, materials, and methods used to develop the OER and the intellectual contribution of the newly adapted OER, and lessons learned are included in the study.

INTRODUCTION

An early attempt to describe Open Educational Resources (OER) was at a UNESCO forum in 2002. This forum defined OER as open educational resource provisions enabled by information and communication technologies to be used for consultation and adapted by a community of users for non-commercial purposes (Hylén, 2006). Similarly, the Common Wealth of Learning (2013) defined the OER concept to include materials freely and openly offered for use and adaptation for teaching, learning, development, and research. For this study, the authors define OER as any resource used for teaching, learning, and research placed in the public domain or released under an open intellectual license permitting its accessibility, usage and reuse, repurposing, and redistribution by others (Atkins et al., 2007). With this definition, an adapted OER's results to improve access and learning in a junior-level electric motor and industrial controls course at a large Midwestern university are presented.

Higher education institutions' current reality is that students, instructors, and researchers invest a significant amount of money towards educational resources. Chris Zook of Applied Educational Systems (2017) states that textbook costs have increased by more than 800% over the past 40 years, with a 400% increase in just the past 15 years. This increase is substantial, particularly compared to an only 250% increase in the consumer price index since 1980. Additionally, almost one-third of post-secondary students reported leveraging financial aid to purchase educational resources. At the same time, two-thirds bought these resources used, and two-thirds did not purchase one or more required resources because of their cost (Zook, 2017).

PURPOSE

To defray educational resources' financial burden for students, the authors adapted existing online OER for use in a required junior-level electric motor and industrial controls course at Iowa State University (Kuphaldt, 2006, 2007a, 2007b, 2007c). This project's motivating objectives were, 1) increase student access to course content through the use of an OER textbook, and 2) improve student learning through the tailoring of the text to course learning objectives. To measure the effectiveness of achieving these objectives, the authors asked the following two research questions:

1. Was students' perceived access positively associated with the adapted OER?
2. Did students who had access to the adapted OER achieve higher levels of learning?

Mr. Oyetunji S. Olaniba is an Industrial and Agricultural Technology Ph.D. student of the Department of Agricultural and Biosystems, Iowa State University, where he currently serves as a teaching and a research assistant. He also has experience working as a graduate assistant, Lean Specialist, and a Physics and Chemistry teacher. His research is focused on the areas of human-machine interaction, 21st-century manufacturing skills gap and competency requirements, curriculum framework development for integration of Lean and Industry 4.0 paradigms, and Lean leadership beliefs, behaviors, and competencies. Mr. Olaniba received both his National Diploma (2005) and Higher National Diploma (2009) in Statistics from Yaba College of Technology, Lagos Nigeria, Post-graduate Diploma in Business Administration from the National Open University of Nigeria (2015), M.Sc. in Technology Management from Central Connecticut State University, CT (2017).

In the remainder of this paper, the authors provide a background of available OER resources, a description of the intellectual contribution made from the development of the project's adapted textbook (Kuphaldt & Haughery, 2020), materials and methods used to measure and infer impacts on student access and learning, and a discussion of the implications and lessons learned. The authors intend that this study will provide others with the encouragement, resources, and proof of concept to adopt, adapt, or develop OERs for their educational venues towards increasing student access and learning.

BACKGROUND

The ability to adapt content is a regularly cited benefit of utilizing OER and a significant component of what makes an open educational resource "open" (Aesoph, 2016; Wiley, 2007, 2014). Adaptations that grow into larger, public projects are possible, as one can see through the well-received *Research Methods in Psychology* series (Chiang et al., 2015; Jhangiani et al., 2019; Price et al., 2018). However, the practice of adapting OERs has not achieved the same level that its use in open education discourse has. Instead, most adaptation occurs at the course level and involves small changes to an OER to better align to the given educational scenario. Similarly, this project began by looking for OER to integrate into an electric motor and industrial controls course and then adapted this resource to align with the class's topics.

The authors implemented the adapted OER in a core course in engineering, but its essence is more applied than introductory. An overview of OER in repositories such as OER Commons (*OER Commons*, n.d.) and the Open Textbook Library (*Open Textbook Library*, n.d.) found examples of open textbooks and learning modules on AC/DC circuits and electricity. Still, few took an applied approach, with many providing only a basic overview of circuit applications. This lack of content is likely due in part to the belief that OER should be widely reusable, an idea that does not facilitate the development of content catered to a course's individual learning outcomes (Windle et al., 2010). The content that came closest to meeting the authors' needs was created by Tony R Kuphaldt (2006, 2007a, 2007b, 2007c) and was, therefore, the basis of the adapted OER used in the course in question.

Due to the breadth of Kuphaldt's content and the authors' course focus, it was necessary to edit and adapt this content to allow for better alignment to the course's learning objectives. Initially, Haughery began to use sections and subsections of Kuphaldt's resources as weekly class reading assignments, provided to students as hyperlinks through the course's LMS. This delivery method allowed for relatively quick and free access to Kuphaldt's content. From an instructional design perspective, though, this delivery method was less than optimal. It lacked continuity and flow because it was a collection of disparate webpage links, many of which had advertisements in the margins. To improve upon this delivery method, the authors completed a collaborative project to adapt Kuphaldt's content to produce a stand-alone OER textbook for the course, with funding support from an Open Education Mini-Grant Program. This funding was co-sponsored by the University Library, the Center for Excellence in Learning & Teaching (CELT), and the Senior Vice President and Provost's (SVPP) office. Additionally, the Department of Agricultural and Biosystem Engineering at Iowa State University provided summer support to Haughery to develop this project.

INTELLECTUAL CONTRIBUTION

The adaptation of Kuphaldt's materials into Pressbooks' editing and publishing platform (Book Oven, Inc., Montréal, Quebec, CA) posed a significant learning experience for the authors. Olaniba was primarily responsible for this transfer and reformatting in Pressbooks. As part of this adaption process, Olaniba completed an introductory course module, made available through the Digital Press at the authors' home institution, that illustrated the functionality of the Pressbooks platform, including importing and organizing content, as well as inserting and editing equations, tables, and media objects. This training module was indispensable to leveraging the Pressbooks platform for the OER adaptation project.

The specifics of the adapted OER textbook included consolidation and adaptation of Kuphaldt's *Lessons In Electric Circuits* textbooks (2006, 2007a, 2007b, 2007c) distributed under the Design Science License (Stutz, 2001) via AllAboutCircuits.com's website (AllAboutCircuits, n.d.). Haughery selected relevant chapters and sections based on alignment to course learning objectives, which were copied,

Abbey K. Elder is the Open Access and Scholarly Communication Librarian at Iowa State University. In her position, she works to expand access to information by educating scholars about the opportunities provided by working in open scholarship. Her handbook for instructors, "The OER Starter Kit," has been used in professional development programs around the United States. In addition to chairing her institution's Open & Affordable Education Committee, Abbey is an administrator for the Iowa State University Digital Press and oversees the open access publishing agreements in place at Iowa State University. Her research interests include the history of open education, approaches to scholarly communications across disciplinary lines, and supporting the advancement of open science.

arranged, and adapted directly into Pressbooks by Olaniba. This process had its challenges, as unneeded HTML-formatted characters were unintentionally copied alongside needed content, altering the entire output file's content formatting and text sizes. Haughery carried out an initial review of the textbook in Pressbooks to resolve global formatting issues and confirm each chapter's alignment with weekly course topics. Through the assistance of Elder, the unwanted characters were then identified and deleted from Pressbooks text pages. Also, issues related to LaTex equation editing and numbering, heading font size, table layout, page formatting, readability, accessibility, and clarity were identified and corrected during an initial review process.

The resulting OER, Applied Industrial Electricity: Theory and Application (Kuphaldt & Haughery, 2020), was published in January 2020 by the author's university Digital Press using Pressbooks in four formats: EPUB, PDF, MOBI, and HTML. The choice of these formats allowed for maximal accessibility by students. Additionally, students were given access to these versions via a hyperlink in the course's learning management system. The use of Pressbooks to deploy the OER also enabled ongoing review and editing to occur in real-time.

The course in which the OER was adapted focused on applications in agriculture and manufacturing. Therefore, the ability to adapt and tailor existing OER content into one consolidated textbook to better serve students was paramount. Specifically, the adapted OER (Kuphaldt & Haughery, 2020) included topics related to industrial power systems (see Table 1). Haughery made topic inclusion decisions based on his 15+ years of educational and professional experience teaching and practicing industrial electronics, controls, and automation. Furthermore, the rationale to focus on motor applications was grounded in the ubiquitous use of electric motors in manufacturing and agricultural processes; electric motors account for nearly 50% of worldwide energy consumption (Waide & Brunner, 2011). Because of these reasons, the authors argue that the adapted OER presented here applies to similar courses focusing on applications in agriculture and manufacturing, mainly applied engineering, engineering, engineering technology, or technology.

Table 1: Table of contents for adapted OER, Applied Industrial Electricity: Theory and Application (Kuphaldt & Haughery, 2020)

TOPICS
• Electrical Safety
• Basic Concepts and Relationships
• Circuit Topology and Laws
• Alternating Current
• Motor Characteristics
• Reactive Power
• Power Factor Correction
• Transformers
• Industrial Controls
• Motor Circuits and Control
• Conductors
• Right Triangle Trigonometry
• Complex Number Review
• Circuit Schematic Symbols
• Troubleshooting - Theory and Practice

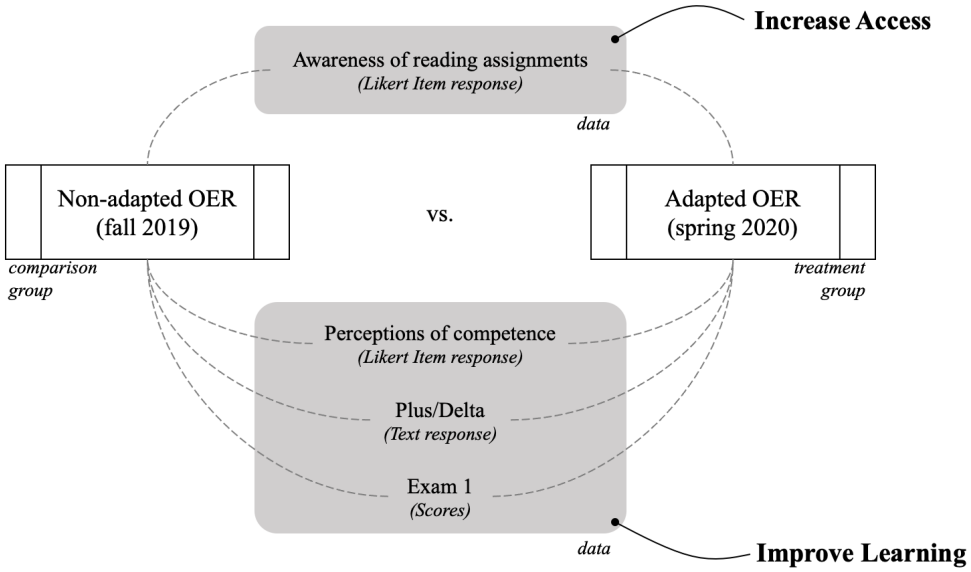
MATERIALS AND METHODS

Design

The authors used a quasi-experimental, non-equivalent comparison vs. treatment group design (Trochim & Donnelly, 2001) to evaluate the effectiveness of the adapted OER to improve student access and learning. The "quasi" designation stemmed from the non-random assignment of participants to each group, with the fall 2019 and spring 2020 semesters of a junior-level electric motor and industrial controls course serving as the comparison and treatment groups, respectively. The authors refer to

these groups as the *adapted OER* (treatment) and *non-adapted OER* (comparison) groups. Figure 1 further illustrates the research design, sample groups, and data streams used to assess the adapted OER's effectiveness.

Figure 1: Illustrated research design, including sample groups and data streams



Context

Since 2018, the junior-level electric motor and industrial controls course sampled from for this study, *Electrical Power Systems and Electronics for Agriculture and Industry*, has migrated from a traditional for purchase hardcopy textbook, to non-adapted online OER weekly course readings (available via hyperlinks in the course LMS), to a stand-alone adapted OER textbook. This course, which is a core requirement for the Industrial Technology and the Agricultural Systems Technology undergraduate programs offered by the Department of Agricultural and Biosystem Engineering at Iowa State University, routinely sees enrollments of 150 students per year. Moreover, the course has two contact hours of lecture and three contact hours of laboratory each week.

The course selected for adaption of the OER focused on applying electrical theory to industrial and agricultural environments. Specifically, Haughery leverages theory towards the design, measurement, and analysis of electric motors to include reactive power analysis and correction, safety circuit design and implantation, transformer selection and configuration, industrial and motor controls, relay ladder logic, conductor characteristics and selection, system troubleshooting, and schematic development and analysis. Emphasis was given to single-phase, split-phase, and three-phase circuits.

Measures

The data used to answer the study's research questions included exam scores and self-reported student survey responses administered to both study groups (see Figure 1). Specifically, exam scores from the course's first exam were collected. This exam included series/parallel circuit analysis, poly-phase circuit analysis, motor characteristics, and motor selection topics. Scores range from 0 – 100 points, with the opportunity for 20 additional bonus points. The authors decided to collect data from this exam because it was the only comparable exam between semesters. The second and third exams were administered remotely online due to the spring 2020 coronavirus pandemic. Student self-reported survey responses were also collected mid-semester, using a Plus/Delta survey (Helminski & Koberna, 1995), and after the second exam, using an informal exam follow-up survey. These formative assessments asked students to reflect on their perception of what was helping them learn and how the assigned weekly readings helped their understanding and competency level at the beginning of the

semester vs. after the second exam.
The authors used survey response data of students' awareness of weekly assigned readings to answer the first research question. Furthermore, students' perceptions of what was helping their learning, perceptions of their competence, and exam one scores were used to answer the second research question related to learning.

Sample
The study collected survey data from n=144 students enrolled during the fall 2019 (*non-adapted OER*; *n*=83) and spring 2020 (*adapted OER*; *n*=61) semesters. As stated in the Design section, these samples were non-equivalent groups. The environment in which the study was conducted dictated the design and sampling method; the project team did not dictate student enrollments in specific course sections (i.e., treatment or comparison). While this research setting is not as devoid of confounding variables as a randomized experiment, it is none the less common in educational research (Trochim & Donnelly, 2001). The practical issue that one should appreciate regarding the quasi-experimental, non-equivalent design type is how narrowly the findings can be generalized. Because the study's purpose was to examine the effectiveness of an adapted OER for improving student access and learning in the "wild" of an undergraduate course, the quasi-experimental, non-equivalent sample design was reasonable and appropriate (Trochim & Donnelly, 2001).

Analysis
The authors used Student's *t*, Kolmogorov Smirnov, and Chi-square ($\chi 2$) tests to compare differences in means in exam scores and survey responses for the two student groups. Hypothesis test results were then used to answer each research question. Additionally, boxplots of the data were examined to identify the presence of outliers, Levene's tests of equality of variance to confirm that the assumption of homogeneity of variance was satisfied, and tests of normality to confirm all data was approximately normal. Other assumptions for the use of *t*, Kolmogorov Smirnov, and $\chi 2$ tests, including continuous scales, two categorical variables, and independent groups, were examined and deemed satisfied. Hypothesis test results were then used to answer each research question, with statistical significance based on and analyses conducted using SPSS 24.

RESULTS AND DISCUSSION

Increase in Access
To answer the question, "Was students' perceived access positively associated with the adapted OER?", the authors evaluated whether the project's adapted OER improved student access. To assess this, the authors analyzed students' self-reported surveys regarding their awareness of assigned weekly readings. Students were surveyed across three consecutive weeks, resulting in 417 data points across the two groups. Specifically, unawareness of the weekly readings was reported 18 times (10%) in the adapted OER group vs. 47 times (20%) for the non-adapted OER group (Table 2). Using a $\chi 2$-test of proportions, this inferred that students in the adapted OER group were statistically more aware of the weekly readings ($\chi 2 = 8.199$, *p-value* = 0.003), representing a small positive effect size of Cramer's $V = 0.14$ towards increased access of the adapted OER.

Table 2: Contingency table of perceived access to the course textbook per group ($\chi 2 = 8.199$, p-value = 0.003, Cramer's V = 0.14)

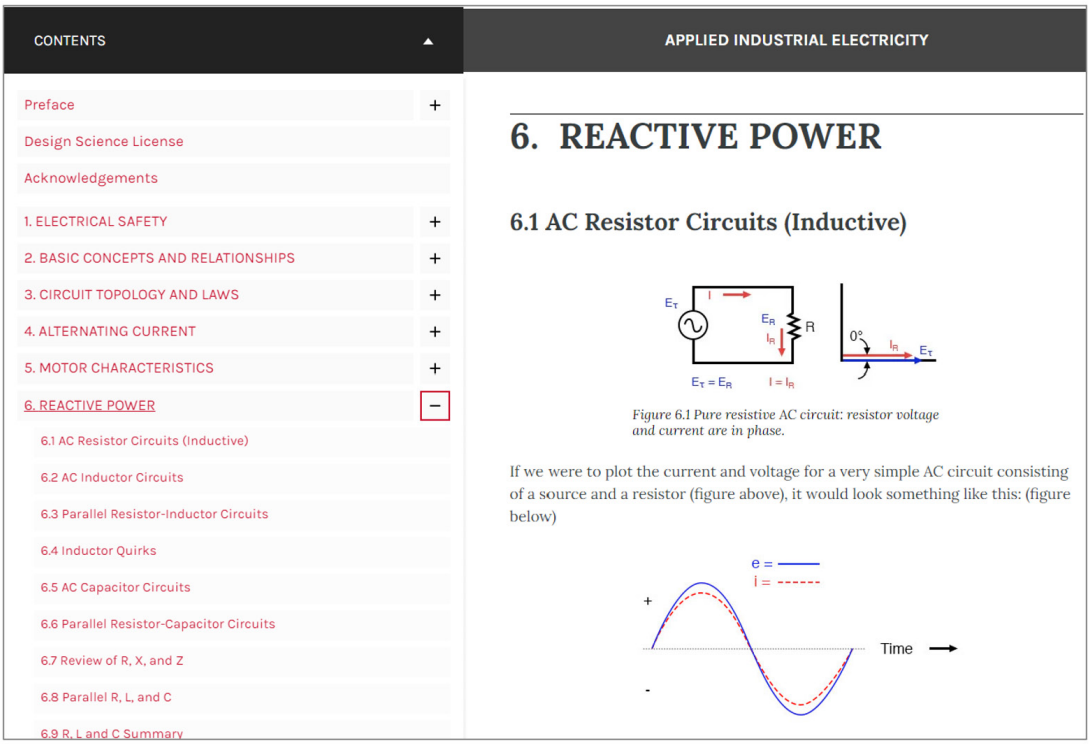
	LEVEL OF ACCESS		
Group	Unaware	Aware	Total
Non-adapted OER	47	87	234
Adapted OER	18	165	183
Total	65	352	417

The authors used the indirect measure of students' awareness of assigned readings because a direct measure of student access (e.g., content access frequency and duration) was impossible. This inability to accurately track access data was due to the course's LMS system's technical capabilities, which

the researchers did not control. Given the statistical results, the adapted OER was more accessible to students. The adapted OER textbook provided a more organized collection of weekly readings vs. the non-adapted OER. Haughery and Olaniba distributed the adapted version as an e-book in EPUB, PDF, MOBI, and HTML (Figure 2). The non-adapted version was a collection of web page hyperlinks that included non-reading related content in the page margins (e.g., advertisements).

Additionally, albeit anecdotally, Haughery observed that more students requested print versions of the adapted OER vs. the previous version (~10% adapted OER vs. ~3% non-adapted version). More research is needed to understand why more students asked for a printed version of the adapted OER and why they were more aware of assigned readings. This study's results reveal a small positive association between students' perceived access and the adapted OER (Cramer's $V = 0.14$).

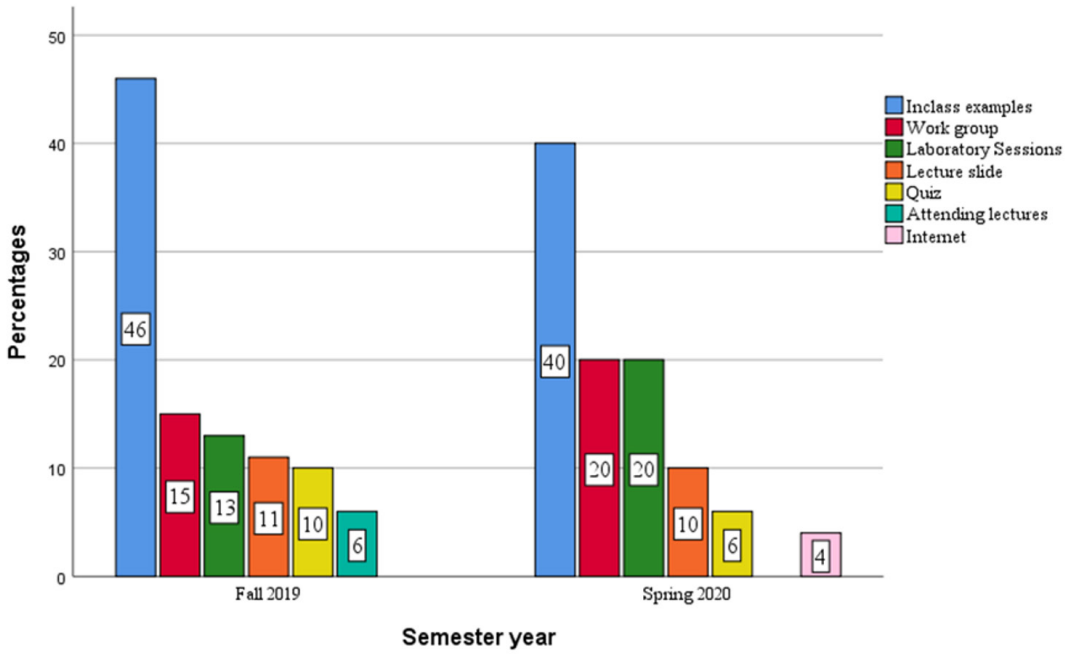
Figure 2: Illustration of web browser accessible version of the adapted OER (Kuphaldt & Haughery, 2020) with hyperlinks (left margin) to chapter sections and subsections.



Improvement to Student Learning

Evaluating whether the adapted OER improved student learning, the study asked the following question, "Did students who had access to the adapted OER achieve higher levels of learning?" To answer this question, open-ended Plus/Delta student survey responses, the authors evaluated Likert item questions and exam scores from the adapted OER and non-adapted OER groups. Examining Plus/Delta responses for what helped students learn in the course, there was no statistical difference in response for students who were given the adapted OER vs. the non-adapted OER. This finding was based on a Kolmogorov-Smirnov Z-test statistic = 0.477 (p-value = 0.977) of the frequency of response types per group. This test evaluated how similar student responses were between groups, with non-significant results implying students did not report different reasons for what was helping them learn (i.e., adapted OER). This comparison is illustrated graphically in Figure 3, which depicts the percentages of student response types with frequencies ≥ 3 per study group (the authors grouped similar responses before conducting the analysis).

Figure 3: Percentages of student response with frequencies ≥ 3 to the question, "What is helping my learning in the course?"



Analyzing students' perceptions of competence with the course's most challenging elements (i.e., applying trigonometry to reactive power analysis of electrical circuits) revealed no statistically significant differences. Specifically, student's perceptions were tested in the adapted OER vs. the non-adapted OER groups and it was found that beginning of semester trigonometry competence was statistically similar ($M_{diff} = 0.08$, $t = 0.445$, *p-value* = 0.657), their change in incompetence to be statistically similar ($M_{diff} = 0.03$, $t = 0.185$, *p-value* = 0.854), and their reactive power competence to be statistically similar ($M_{diff} = -0.05$, $t = -0.249$, *p-value* = 0.804). Based on these results, student learning of trigonometry and reactive power content (the most complex topics of the course) did not increase or decrease for those given the adapted OER. It is important not to overlook the fact that student learning did not decrease. It was no worse than the baseline textbook.

Finally, the authors evaluated student scores on the first exam (see Table 3). This exam included series, parallel, poly-phase circuit analysis, motor characteristics, and motor selection content. Based on a *t*-test of means for this exam, students who were given the adapted OER vs. the non-adapted OER did achieve statistically higher scores ($M_{diff} = 4.85$, $t = 2.049$, *p-value* = 0.042). While this represented a small effect size, based on Cohen's $d = 0.35$, the adapted OER improved student learning for the first exam. This result, combined with the other non-significant differences in students' perceived competences with trigonometry and reactive power analysis, led the authors to infer a marginal impact of the adapted OER on student learning (the authors did not analyze other exams and final course grades due to differences in remote vs. in-person course modality and student mental bandwidth brought on by the coronavirus pandemic of the spring 2020 semester). The results show the adapted OER as effective at improving student learning and should continue to be used in the course.

Table 3: Descriptive statistics of Exam 1 grades for students who were given the adapted OER textbook vs. those who were not ($M_{diff} = 4.85$, $t = 2.049$, p-value = 0.042)

Group	n	M	SD	Min	Max
Non-adapted OER	83	89.50	15.21	26.0	114.5
Adapted OER	61	94.35	12.24	63.0	113.0

Implications

While the study results show small increases to access and learning for students who were given the adapted OER vs. those who were not, implications are farther reaching. The adapted OER, while similar to the non-adapted OER from a content perspective, was much different from the previous traditional course textbook. This conventional textbook was heavily geared towards agricultural applications and moderately expensive (~$50). Furthermore, this previous text was miss-aligned with a few vital industry-relevant competencies, including sensors, motors, actuators, motor overloads, arc flash, intrinsically safe, and explosion-proof. Furthermore, the use of conventional terms used in Ohm's Law, reactance, and power factor relationships did not follow industry norms. Finally, the previous textbook was written in a grammatical style that was hard for students to understand.

On the other hand, the adapted OER textbook allowed students to make broader connections to applications in electrical power and industrial controls. Furthermore, the e-versions of the adapted OER have saved students a combined $8,000 per year. This savings equates to close to $50 per student, which is significant, considering many students enrolled in the course self-fund tuition, room, and board.

Furthermore, while not an intended implication of this project, the adapted OER quickly augmented the course's online instructional format during the coronavirus pandemic. This unintentional benefit stretches beyond the course in question. Because it is an OER released under the Design Science License (DSL), other educators are free to adopt, adapt, remix, or reuse its content, assuming these educators include the DSL terms and conditions (Stutz, 2001) with the OER. While quickly moving courseware online is not ideal, higher quantity course content will migrate to this medium, allowing education to increase course openness and accessibility. The adapted OER is ready to support instructors and students' growing accessibility requirements (Flaherty, 2020).

Finally, adapting the OER has allowed the instructor (first author) to tailor the content to better align with the course's specific learning objectives, thus enabling the OER to be of greater relevance to students. This relevance is especially significant, given the course's uniqueness, which takes an applied approach to poly-phase electrical circuit design and applications that are focused on electric motor loads.

Lessons Learned

While the conversion, formatting, and publishing process of this OER adaptation project was straightforward, it consumed a significant portion of Olaniba's workweek (about 10 – 15 hours per week) for the summer and fall of 2019. Furthermore, Olaniba devoted much of his initial time to learn the interface and functionality of Pressbooks, as this platform was new to him. However, this offered Olaniba a professional development opportunity. Here, the authors do not intend to deter other educators interested in pursuing OER projects by conveying a picture of long hours and a steep learning curve. The authors simply intend to clarify the time involved to complete the straightforward adaption process (i.e., no new content was developed, only existing content was reformatted and repackaged). This clarity is meant to help those pursuing similar projects, allowing them to create accurate project timelines.

Concerning students' motivation to leverage the adapted OER towards their learning, the authors observed that most did not. To improve the OER's effectiveness, Haughery and Olaniba explicitly communicated with students throughout the semester regarding the availability, value, and benefits of reading the textbook. Additionally, weekly pre-class quizzes were given to students to encourage accountability to complete assigned readings. Based on Plus/Delta and end of semester evaluation of instruction results, many students felt that these pre-quizzes should focus on conceptual vs. analytical questions. Students felt that conceptual questions would more appropriately test their understanding of theory after completing the weekly reading assignments. In contrast, analytical questions would test their ability to apply theoretical knowledge to design and analysis problems after attending the lecture. These pre-quizzes were revised to include multiple-choice and true/false type conceptual questions aligned to assigned weekly readings. The authors anticipate that subsequent iterations of the course will result in students' increased usage of the adapted OER.

CONCLUSION

This project adapted an OER textbook (Kuphaldt & Haughery, 2020) for use in Iowa State University's junior-level electric motor and industrial controls course to improve student access and learning. Based on survey and exam data collected before and after its implementation, the authors found the adapted OER to be effective at improving access and learning while also saving enrolled students $8,000 per year, collectively. Moreover, the authors presented details of the project's intellectual contribution, the adaption process, the content topics included, and lessons learned. This project's results provide a resource to educators adopting, adapting, remixing, or reusing OER content in applied engineering, engineering, engineering technology, or technology undergraduate courses.

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