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Open Educational Resources for Supporting Engineering Education

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Abstract

Discussion of Open Educational Resources (OER) is often limited to textbook cost but it is the flexibility and customizability of OER that makes them a best choice for education. To truly succeed OER projects need to provide not only textbooks but tools and other resources needed today and they need to do so in a way that makes it simple (or as simple as possible) for instructors and students. Platforms for OER must and are becoming educational ecologies with services such as annotation, adaptive homework systems, collaboration tools and more. Engineering and STEM OER has particular demands, including LaTeX equation editing and the ability to execute programs within the textbook. They also must, and are, being extended to be accessible to all, where accessible not only supports those who have difficulty reading, but also those who do not have easy access to devices or the internet. Rather than a loose assembly of EdTech apps, OER system design requires components that support each other. At Prince George's Community College we have built open textbooks for community college engineering, chemistry and physics courses for engineering students using LibreTexts. A major virtue of OER textbooks is that they can be improved formatively as instructors work with their classes. On the technical side, as new components such as a branded school OER commons, a project management app and an online homework system become available they can be integrated to work with the ongoing materials. These textbooks have supported past, current and future curriculum redesign including a new Associate of Science degree in Chemistry and a planned one in Physics.

Introduction

Engineering and other STEM programs are confronted by students taking substantially more than four years to graduate [1, 2]. In the case of community colleges, mismatches with university curricula substantially prolong the time to bachelor's degree graduation and even lead to attrition [3, 4]. Coordination of engineering, chemistry, physics and mathematics courses to minimize duplicated material will lead to faster graduation rates and less attrition. Coordination of STEM curricula at community colleges with the universities students articulate to is a must [5, 6].

Today we stand at the threshold of a revolution as openly licensed online materials support customization of textbooks to meet the needs of each instructor and their students. Educational materials are escaping the one size fits all straitjacket, as they must, to meet the challenges of increasing diversity of students given today's complex learning requirements.

Textbooks have been with us since scribes first wrote. Printing democratized education as presses became faster and paper more available. The limited ability to customize material for

students was a messy business, with typewriters, carbon paper and mimeograph machines but grew as photocopying became available, less cranky and affordable. Starting about 40 years ago teachers used copy shops to provide custom materials for their courses. With the Internet, these samizdat moved online, mostly as pdf files.

Textbook Economics

The fuse igniting OER adoption was lit by the high costs of commercial textbooks [7] supported by marketing to faculty through supporting services and ancillary materials [8]. Since students pay, cost is unrestrained. The parallels with the pharmaceutical market are exact as shown in Table 1. Textbooks are a business to business market [9] where a trusted broker, faculty, chooses what is to be bought by the customer, the student. The broker almost never collects payment or provides the book, although in many cases, an associated agent, the institutional bookstore does. Both are characterized by an inelastic demand curve where the price is independent of sales and the number of sales depends on marketing to the prescriber.

Table 1. Business to Business model of the textbook and pharmaceutical markets.

Source	**Prescriber**	**Associated Intermediary**	**Buyer**
Commercial Publisher	Faculty	Bookstore	Student
Pharmaceuticals	Physician	Pharmacy	Patient

Until about 2015 the textbook market was the perfect storm for commercial publishers [10]. Textbooks were marketed to trusted prescribers, the faculty, who seldom knew the cost to the payers, the students. Faculty received support from the publishers with test banks, presentation decks, instructor's manuals and the occasional dinner. The students were faced with awful choices if they could not afford the textbooks. This included not taking a course, dropping the course, having to change major, getting lower grades or buying the expensive textbook, in some cases instead of food [11]. This is particularly the case in STEM fields where the cost of a single book could exceed $300 [12].

Textbook bloat is a result of this model, publishers include every possible topic in their textbooks because not having a chapter on the favorite issue of a faculty member running a large enrollment course could cost millions of dollars in sales. Printed STEM books have more than doubled in weight over the past 50 years.

Resistance arose from used textbook vendors, textbook rental programs and students copying or simply not buying the books to their detriment. Publishers reacted by marketing rentals, packaging homework systems that faculty require students to use and selling inclusive access programs to bookstores and administrators [13], infringing on the rights of faculty to choose materials for their courses. Over the course of the last decade students and their parents complained mightily to each other, their teachers and institutions and lawmakers about the high

cost of textbooks. Organizations such as the Public Interest Support Group, and SPARC took up the issue [14, 15] and they were heard, with state higher educational boards and legislatures encouraging efforts to lower textbook costs [16].

Foundations such as the Gates, Mellon and Packard Foundations provided and continue to provide seed funding for lower cost textbook efforts [17], but government, at the state and national levels have increasingly joined in [18]

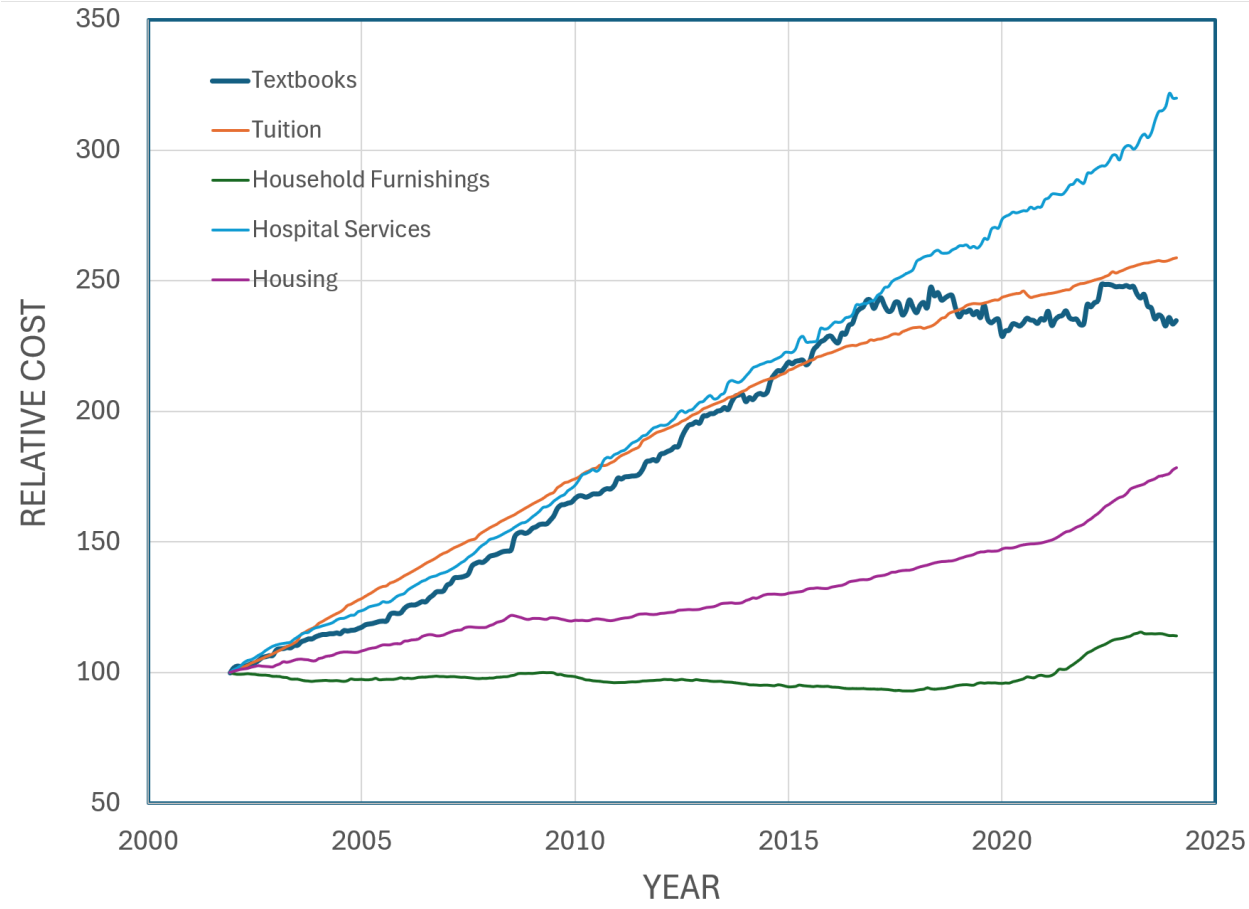

Figure 1. Relative price changes in the current century until February 2024 for college textbooks and other services using Bureau of Labor Statistics data [19].

Since 2018, as shown in Fig. 1, the cost of college textbooks has plateaued as a result [19] of competition. The market drivers for commercial publishers have shifted to online homework systems, online and printed book rentals and inclusive access agreements with institutions [13].

Opening the market for OER

The development of open licensing offered a way to reduce textbook costs. The GNU open license and Creative Commons return copyright to its roots. As Pierre Laval put it in his analysis of the Fair Use Standard [20] “copyright is not an inevitable, divine, or natural right that confers

on authors the absolute ownership of their creations. It is designed rather to stimulate activity and progress in the arts for the intellectual enrichment of the public." The Delhi High Court used exactly this language when considering a suit brought by commercial publishers against a copyshop, ruling that copying for educational purposes was fair use [21]. Knowledge is a gift not a commercial good. Supporting creators is an important but not the only goal and certainly not support for commercial enterprises except in so far as they advance intellectual activity. This is the vision of those supporting OER creation and use. The high cost of textbooks created a crisis for students. Surveys show that over half of students report not buying textbooks for classes, almost half have taken fewer courses and many report earning lower grades or dropping because they did not have the textbook [11].

To meet those goals, platforms for OER creation have been built in the last decade. UNESCO defines OER as "teaching, learning or research materials that are in the public domain or released with intellectual property licenses that facilitate the free use, adaptation and distribution" [22]. These systems and their associated repositories and referatories enable teachers to create, publish, locate and share textbooks and other resources. The COVID crisis accelerated the move to OER because of how OER can be tightly coupled to virtual lectures and direct internet availability. When there was no campus bookstore for acquiring textbooks, instructors could get online books to students by providing a URL. If the book was an OER, the cost was zero [23].

As OER development has shown, money is not the only reward. Institutional and community regard can motivate creators. Small granting programs, supported by individual institutions [24], state level programs [25] or national agencies [26] for creating textbooks have produced a great deal of quality instructional material. Besides money, usually equivalent to a few weeks salary, reduced teaching loads are important to faculty as is the respect of their colleagues and students for jobs well done. Both institutions and the individual faculty benefit from the external visibility of their OER when it is available to others online. This visibility can motivate enrollment of new students, including international students. Finally, national granting agencies now ask for broader impact, a category which fits OER research, creation and implementation.

What do OER Platforms Need to Compete with Commercial Offerings?

Bay View Analytics has been surveying faculty attitudes toward and needs for OER for over a decade [27]. Fig. 2 shows the results for what curricular materials are required for classes, with an online homework system being increasingly important. The figure below is a bit misleading because some instructors only want printed textbooks, others only online ones and many are agnostic. Faculty still hold textbooks to be the most important educational resource, but the availability of an online homework system is a major driver of textbooks choice. For STEM the availability of Jupyter notebooks for in book computing and interactive visualization can also be decisive.

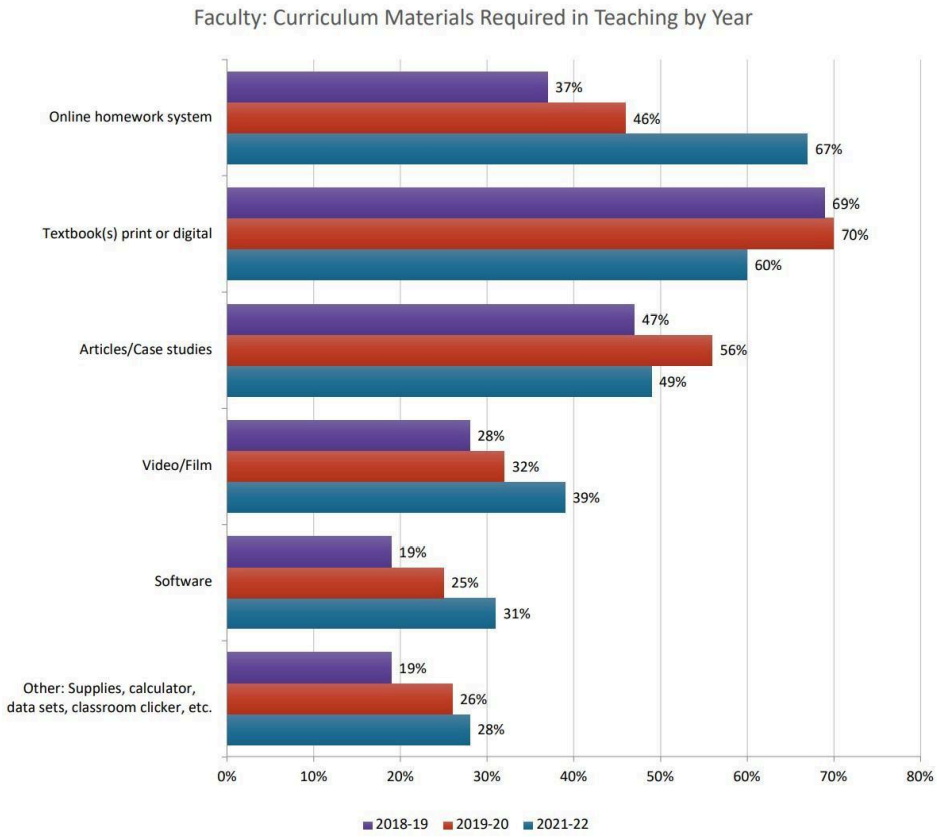

Figure 2. Bay View Analytics survey of curriculum materials required for classes by faculty. CC-BY [27]

To compete OER platforms must and are becoming educational ecologies with services such as annotation, homework systems and more. They also must, and are, being extended to be accessible to all, where accessible not only supports those who have difficulty reading, but also those who do not have easy access to devices or the internet. In the US the two leading platforms for custom OER creation are LibreTexts [28] and Pressbooks [29]. Creation and customization is a *sin qua non* for reaching diverse audiences. Other systems such as OpenStax [30] and Lumen Learning [31] provide free online access to composed texts with limited available customization possibilities. About a quarter of students and instructors want printed copies and printing does carry a cost.

Curriculum Design

OER provides the toolbox for modernizing STEM education, but curriculum improvements must provide the design. Improving the first two years of STEM education was the first priority for the Council of Advisors on Science and Technology (PCAST) [32]. The American Association of Community Colleges discusses how it is necessary to move from isolated courses to coherent curricula [33]. The National Science and Technology Committee knows that STEM education requires ecosystems where partners support each other in complex, but integrated, projects [34].

Community colleges are the gateway to higher education for disadvantaged people [35] and particularly so for under-represented minorities in STEM. The costs of textbooks and today, homework systems, can exceed community college tuition, still the economic return from attending community college is comparable to four year schools [36]. Community college students suffer transfer shock when moving to major research institutions, and attrition is high [37, 38, 39]. It is even more of a problem for STEM students where courses are sequential and often have prerequisites.

Engineering curriculum redesign goes hand in hand with STEM curriculum redesign because engineering students all take math, physics, chemistry and computer programming courses. It is imperative to knock down departmental silos to have a coordinated curriculum for majors . This is a trice easier in community colleges where physical science and engineering faculty often are in a single department or unit.

Case Study - Curriculum Redesign at Prince George's Community College

Redesign started at Prince George's Community College with a one semester chemistry course for engineers that stripped out content taught in General Physics, and de-emphasized biology topics relevant to pre-med students while infusing materials science concepts. The assumption was that engineering students have better mathematical preparation than most who take general chemistry, including at least the first semester of calculus, and that their high school work and the Introduction to Engineering Course that they take in the first semester will have covered many of the preliminary subjects that are found in a typical general chemistry course such as SI units, etc. Engineering majors with the exception of chemical engineers only take one semester of General Chemistry, usually the first, emphasizing bonding, thus missing out on kinetics, equilibrium and thermochemistry, which they need [40, 41]. To date there have been over 700,000 pageviews of the CHEM 2000: Chemistry for Engineers book [42], with the vast majority coming from outside the college and the majority from outside the United States (Fig. 3).

It was one of the first OER books at Prince George's Community College and played an important part in obtaining a NASA grant to improve Engineering, Physics and Chemistry laboratories, create other Engineering courses and provide stipends for our community college students to conduct research at NASA. It set the stage for our community college to be a partner in a large Department of Education grant for open textbooks. That funded creation of over 60 additional free and open textbooks now housed in the college commons on LibreTexts [43]. By Fall 2022, these OER books were used in over 1,000-course sections, impacting over 15,000 students.

Among the OER textbooks built are Introduction to Engineering for Engineers and Scientists [44], General Physics [45, 46] and Calculus [47]. To improve them we are currently building online formative and summative assessment into the textbooks.

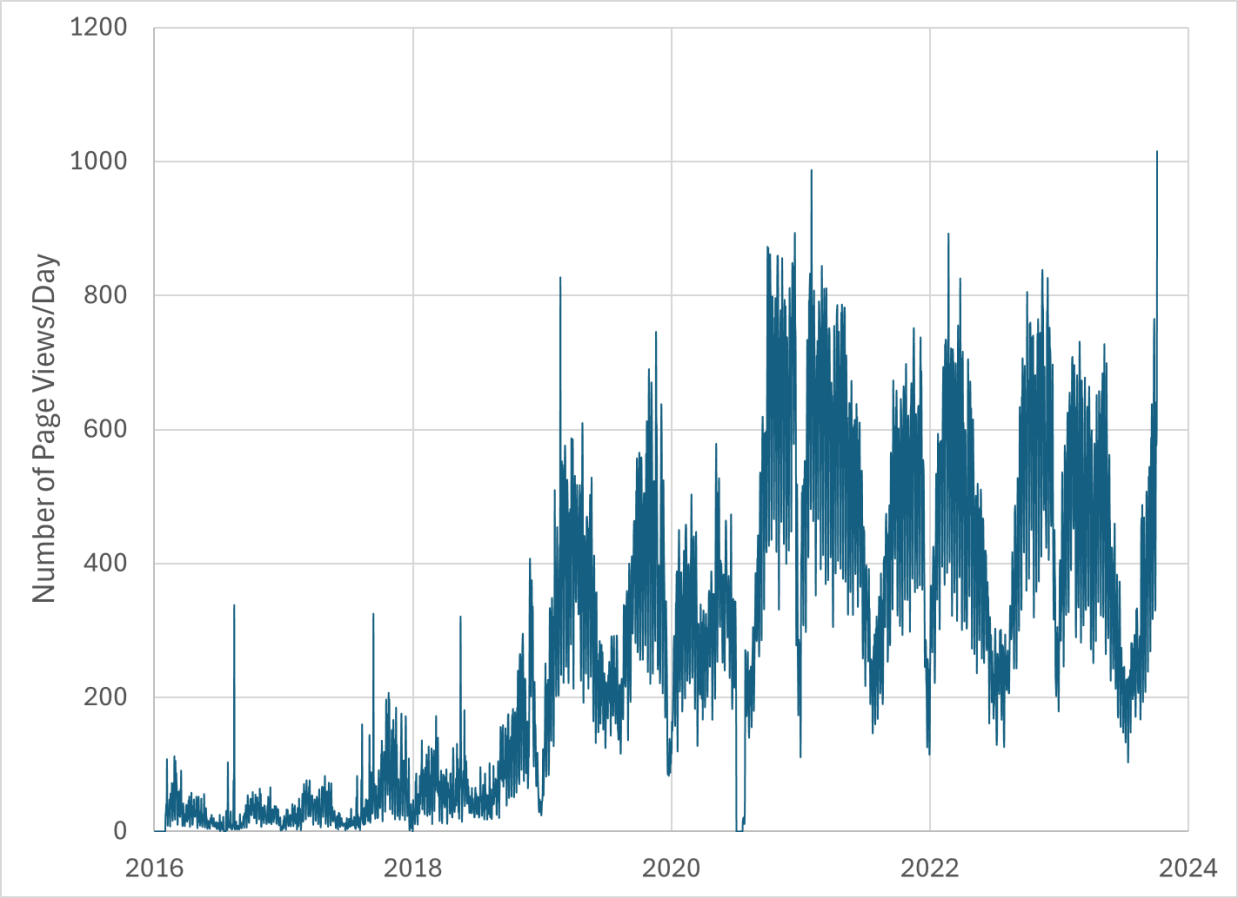

Figure 3. General Chemistry for Engineers daily pageviews from Google Analytics.

Following on the principles used in creating the Engineering Curriculum, a new CHM AS degree at Prince George's, will enable seamless transfer without delays imposed by mismatches between curricula at two and four year institutions. Teaming with colleagues at the University of Maryland, College Park where many Prince George's Community College students complete their bachelor's degree, this addresses the culture gap between neighboring community colleges and universities [48].

Chemistry majors take physical chemistry the first semester of their junior year. The CHM AS prepares students to immediately enroll in physical chemistry their junior year at the transfer institution. Chemistry students with AA degrees were not required to take the calculus-based physics lecture and lab, which are prerequisites for physical chemistry. This created a two-term delay before chemistry transfers could enroll in physical chemistry. The new curriculum requires that the chemistry majors take two semesters of calculus-based physics in community college, which will improve their chances of obtaining the bachelor's degree in four years. OER textbooks will be built to support this new major, as they did the Engineering curriculum.

A second major focus will be to enhance General Physics courses and especially the new General Physics Laboratory courses which are basic elements of the CHM AS degree with the goal of

building toward a Physics Associate of Science degree (PHYS AS). OER textbooks are being built for these courses [45, 46]. Finally, OER, and the awards that it helped us win, has played a significant role in building relationships with faculty at the University of Maryland College Park where our students articulate and generally raise our visibility online.

Conclusion

At Prince George's Community College OER has been used to implement new engineering, science courses by providing zero cost instructional materials for students. The material increased student engagement and understanding and relieved financial stress. Textbooks are static, OER can and is continually improved. Perhaps most intriguingly OER opened the door to creating new and needed curricula.

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