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A Student-Created, Open Access, Living Textbook

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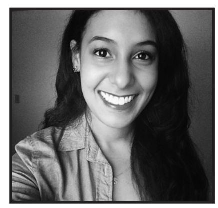
Most courses in engineering use textbooks to supplement lecture-style learning. Other materials are possible, such as online modules, peer-reviewed literature, etc., but most core engineering courses rely on textbooks. A recent analysis of a small cohort of students suggests that students do not use textbooks in the way that they are intended.[1] Furthermore, although textbooks are widely used in engineering classes, less than half of students may read them regularly.[2] Although it is likely that these studies are more reflective of textbook use in large service classes than in the core curriculum of chemical engineering, there is a clear disconnect between the lack of perceived usefulness of these books and their very high cost. Increasing textbook reading is a key objective, as there is a positive correlation between the percentage of students reading a textbook material and the course grades.[3] However, statistics show that 25-30% of students do not read the course textbook.[4] Berry, et al. conducted a study to understand student textbook usage and study habits and found that even though students know that meeting the reading expectations will affect their grade, most students still do not read the textbook.[5] To encourage and incentivize reading, Durwin and Sherman concluded that instructors should not only be concerned with the content coverage in a textbook, but also student preferences of textbook format, such as style, e-books, or online sources.[6] Wankat and Oreovicz refer to results from a higher education questionnaire, where 89% of all students enjoyed the use of an e-book because it as easy to search, inexpensive, convenient, and has increased possibilities of interaction with the content.[7]

Furthermore, the ever-increasing breadth and depth of knowledge in certain fields means that either textbooks become antiquated, or that the authors and publisher must constantly update them. However, the release of updated textbook editions



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in order to stay current with cutting-edge developments often makes resale and the purchase of used textbooks prohibitive. Online versions of textbooks are slowly being adopted by certain fields,[8] and they help alleviate cost for students. To augment this approach, we suggest a mechanism to allow online textbooks to be editable in real time as the field changes, without requiring new printing and textbook editions.

Here, we discuss our approach at the University of Massachusetts Amherst to replace the traditional textbook platform with a student-created, open-access, living (editable) platform. We used Wikis hosted at openwetware.org to allow students to create and update their own textbooks. Wikis are chosen by students, integrating the idea of a flipped classroom[9] with student self-directed learning. This has been a particularly successful approach in Tissue Engineering (CHEM-ENG 575, UMass-Amherst), because this field is rapidly changing and is well suited for topical discussions. We also discuss its application in a new course at the university, Microfluidics and Microscale Analysis in Materials and Biology (CHEM-ENG 590E, UMass-Amherst), which couples the classroom and textbook-style learning with hands-on design projects.

Another positive result from the Wiki implementation is that we pair the textbook page creation with a 10-minute student-led lecture on the topic. A known drawback of traditional 50-75 min lectures (which are the standard at UMass-Amherst) is that they exceed the attention span of a typical undergraduate student.[10] However, longer lecture times are often preferable for faculty, to cover topics more in-depth with less interruption. The challenge is integrating these two ideologies without sacrificing depth of material. Implementation of a student lecture, even a short one, helps break up the traditional lecture format, because the topics will change within that time period, as well as the presenter and speaking styles. Furthermore, these types of short lectures provide frequent opportunities for discussion and input. Another obvious output from this approach is that individual students have an increased depth of learning on their individual topics because of the preparation required to design both a Wiki page and a lecture. We have seen positive student reactions to the combination of a flipped classroom and a student-created textbook, and discuss its creation and potential applications.

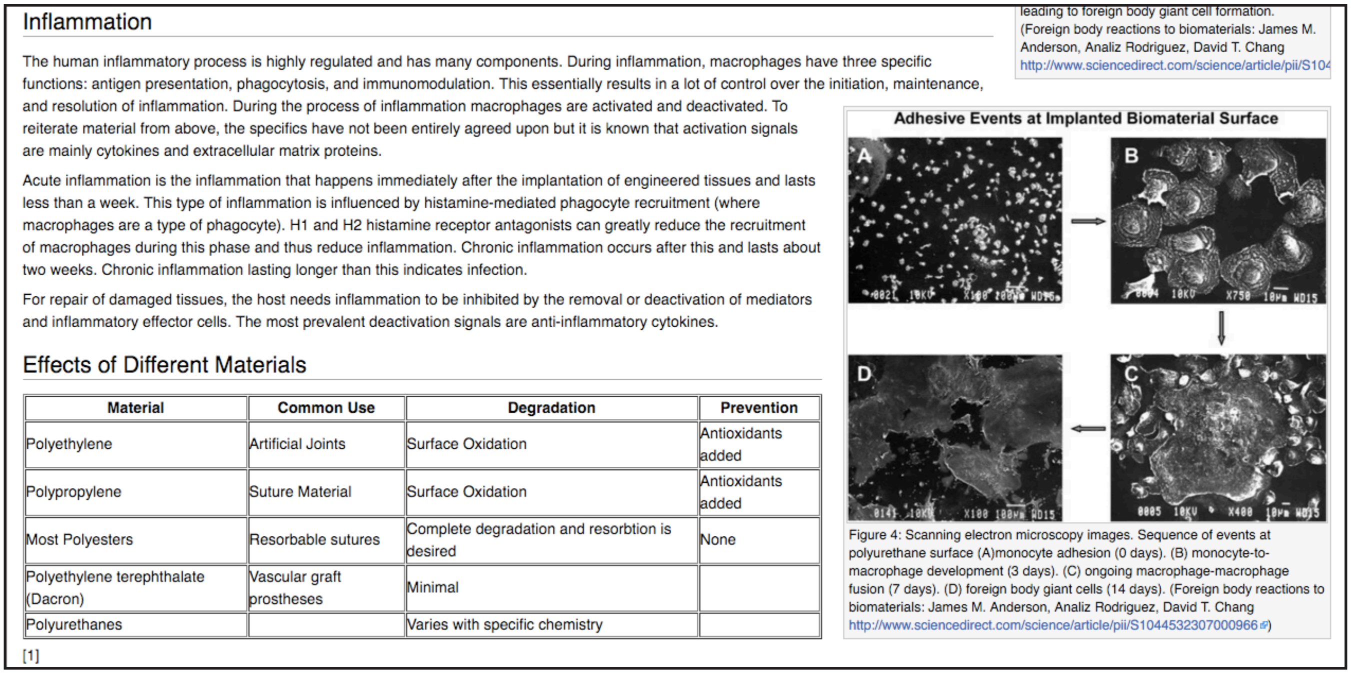
WHAT IS A WIKI?

Wikis are online sources of information that use an open-source, easy to learn coding language that can be easily edited by the community. The most commonly known conglomerate of Wiki pages is hosted by Wikipedia, which is maintained by a non-profit group.[11] Our Wiki resource is hosted by openwetware, which is run by the BioBricks foundation, a non-profit organization interested in broad dissemination of biotechnology knowledge.[12] Similar online resources that are actively edited by the scholarly community include Scholarpedia[13] and Wikibooks.[14] Wikis have grown in popularity at universities, particularly as a way to encourage collaborative writing and group exercises in the classroom.[15,16] More and more educators are incorporating Wikis into the classroom, including within capstone course requirements.[17] These types of collaborative pages are particularly useful for online classes and distance learning.

While Wiki pages encourage student contributions and promote effective collaboration and peer assessment, other popular platforms like Edu2.0, VLE (Virtual Learning Environment),[18] and Moodle[19] are also popular choices for e-learning. Web 2.0[20] tools allow students to get easy access to class material provided by the instructor, but lack an incentive for students to contribute to the site. An advantage of these interactive learning sites is the use of online forums. These allow students to introduce questions after class or extend an existing discussion. Wiki pages encourage collaborative learning by promoting in-class discussions, where students can elaborate persuasive arguments with knowledge gained from their research. Since both options provide complementary advantages, some instructors have explored the integration of Wiki pages with Moodle blogs for the classroom.[21]

Very simple, easy to use instructions exist on openwetware on how to set up a Wiki. An example of our Tissue Engineering course website as a Wiki is shown at <http://openwetware.org/wiki/ChemEng_590B>. Similarly, the course website for Microfluidics and Microscale Analysis is available at <http://openwetware.org/wiki/CHEM-ENG590E>. Course websites can also be advertised on the openwetware home page under "courses." We suggest creating a header template that can exist all throughout the course website, with links to important course information and the textbook, as we have done. Students can then easily copy and paste this header into their Wiki pages, so that there is a consistent look, feel, and navigability to the pages throughout the entire class. Wikis are very accessible for students because they do not need any prior knowledge of coding to create a page. Instructions are available on the openwetware homepage and are very easy to follow. Furthermore, students are welcome and encouraged to view and copy existing layouts from the wiki pages created by the previous year's student, thereby developing skills through active involvement and task-specific problem solving.

Another advantageous aspect of the Wiki format is that the instructor (and anyone else with an account) can monitor the type of edits being made to any page, as well as the author of any edits. This can help with the obvious possible problem of plagiarism, since the authors are viewable. Such oversight also helps to identify if anyone outside of the class has made changes to course content. Openwetware maintains all previous versions of the pages, making it very easy to revert to old versions, if necessary, with a single click. We check for plagiarism on every submission using TurnItIn, which compares the student's Wiki page against web content, peer-reviewed literature, and textbooks.



leading to foreign body giant cell formation. (Foreign body reactions to biomaterials: James M. Anderson, Analiz Rodriguez, David T. Chang http://www.sciencedirect.com/science/article/pii/S104

Inflammation

The human inflammatory process is highly regulated and has many components. During inflammation, macrophages have three specific functions: antigen presentation, phagocytosis, and immunomodulation. This essentially results in a lot of control over the initiation, maintenance, and resolution of inflammation. During the process of inflammation macrophages are activated and deactivated. To reiterate material from above, the specifics have not been entirely agreed upon but it is known that activation signals are mainly cytokines and extracellular matrix proteins.

Acute inflammation is the inflammation that happens immediately after the implantation of engineered tissues and lasts less than a week. This type of inflammation is influenced by histamine-mediated phagocyte recruitment (where macrophages are a type of phagocyte). H1 and H2 histamine receptor antagonists can greatly reduce the recruitment of macrophages during this phase and thus reduce inflammation. Chronic inflammation occurs after this and lasts about two weeks. Chronic inflammation lasting longer than this indicates infection.

For repair of damaged tissues, the host needs inflammation to be inhibited by the removal or deactivation of mediators and inflammatory effector cells. The most prevalent deactivation signals are anti-inflammatory cytokines.

Effects of Different Materials

Material	Common Use	Degradation	Prevention
Polyethylene	Artificial Joints	Surface Oxidation	Antioxidants added
Polypropylene	Suture Material	Surface Oxidation	Antioxidants added
Most Polyesters	Resorbable sutures	Complete degradation and resorbtion is desired	None
Polyethylene terephthalate (Dacron)	Vascular graft prostheses	Minimal	
Polyurethanes		Varies with specific chemistry	

[1]

Adhesive Events at Implanted Biomaterial Surface

Figure 4: Scanning electron microscopy images. Sequence of events at polyurethane surface (A)monocyte adhesion (0 days). (B) monocyte-to-macrophage development (3 days). (C) ongoing macrophage-macrophage fusion (7 days). (D) foreign body giant cells (14 days). (Foreign body reactions to biomaterials: James M. Anderson, Analiz Rodriguez, David T. Chang http://www.sciencedirect.com/science/article/pii/S1044532307000966)

Figure 1. *Excerpt from the student-created textbook page on "Macrophages and their Interactions with Engineered Tissues." This page is taken from Chapter 7 of the Wiki textbook on Immunology. Students discuss immune cell adhesion to different implanted materials and the implications for tissue engineering.*

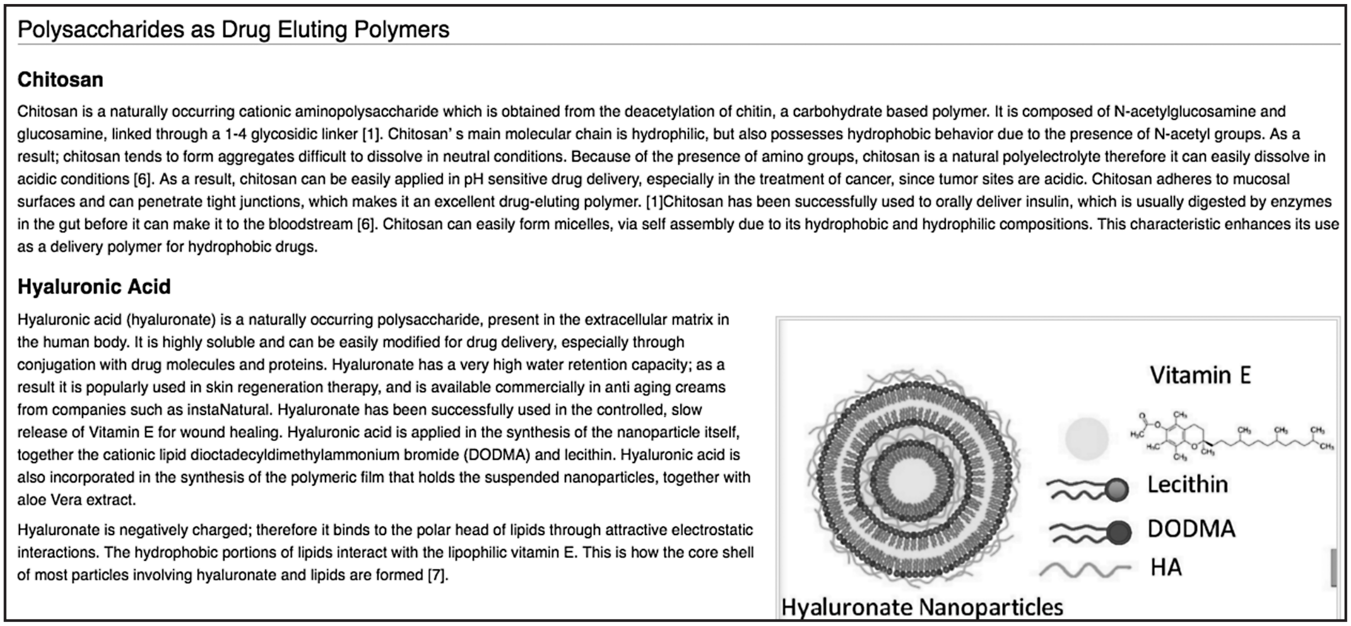
STUDENT-INITIATED AND STUDENT-DIRECTED PROJECTS

We started creating the first 12 Wiki pages in the first year of the Tissue Engineering course (2012) as a way for students to research and disseminate knowledge, in their own words, on a topic of their choosing. As the course has continued, new pages (and updates of existing pages) have allowed this online resource to grow rapidly, to 72 original pages through the fifth year (2016). These Wiki pages are now the fully open-access, student-created, living textbook for this class. Functionally, the development of these pages is handled as a key assignment in the course. On the first day of the course, the instructor hands out a sign-up sheet to the students. Topics are pre-chosen by the instructor and these include new topics that are not yet covered in the textbook, or existing pages that need updating or improvement from previous years. The rubric we have implemented for grading these online textbook pages covers six main facets: (1) the history of the device covered must include a human health motivation and a timeline acknowledging the people and places key to the device/topic invention/evolution; (2) there must be a section on the human health topic it is tackling; (3) side effects or procedures involved must be discussed both concerning the new device and the gold standard; (4) the page must include a descriptive figure or illustration (with citation for re-use, if necessary); (5) the page will be checked for proper grammar, spelling, and for plagiarism; and (6) the page must have a minimum of five, peer-reviewed references cited.

Topics are pre-assigned to a presentation and due date, which are matched to the lecture schedule of the class. Each Wiki page created is associated with a student lecture (10-15 min in length). This, again, reinforces student motivation for learning a particular topic with great depth. Also, it allows other students in the class to ask their peer questions during the lecture. Many students feel more comfortable asking questions of a peer rather than the course professor, which highlights a learning advantage for the whole class. The professor is present during the Wiki presentation to help clarify and answer questions as well.

The progression of our Tissue Engineering course is flexible, but follows a logical sequence each semester, created by the instructor. We cover the motivation and need for engineered tissues, a brief history of biomaterials, how human cells interact with materials, immunology, and then how to direct cell and tissue function both ex vivo and in vivo. Topics for the Wiki presentations and textbook are preassigned to a specific date to match with the progression of the course. Then, students can choose any of these topics they are interested in. Background lectures are given by the instructor before the wiki due date, to tell students the most important information to cover in their own wiki. We have found that incorporation of student choice increases the investment in their topic more than if they were assigned a wiki.

Over five years of the Tissue Engineering course, our students have built a textbook that covers background and introductory topics, as well as pages related to special



Polysaccharides as Drug Eluting Polymers

Chitosan

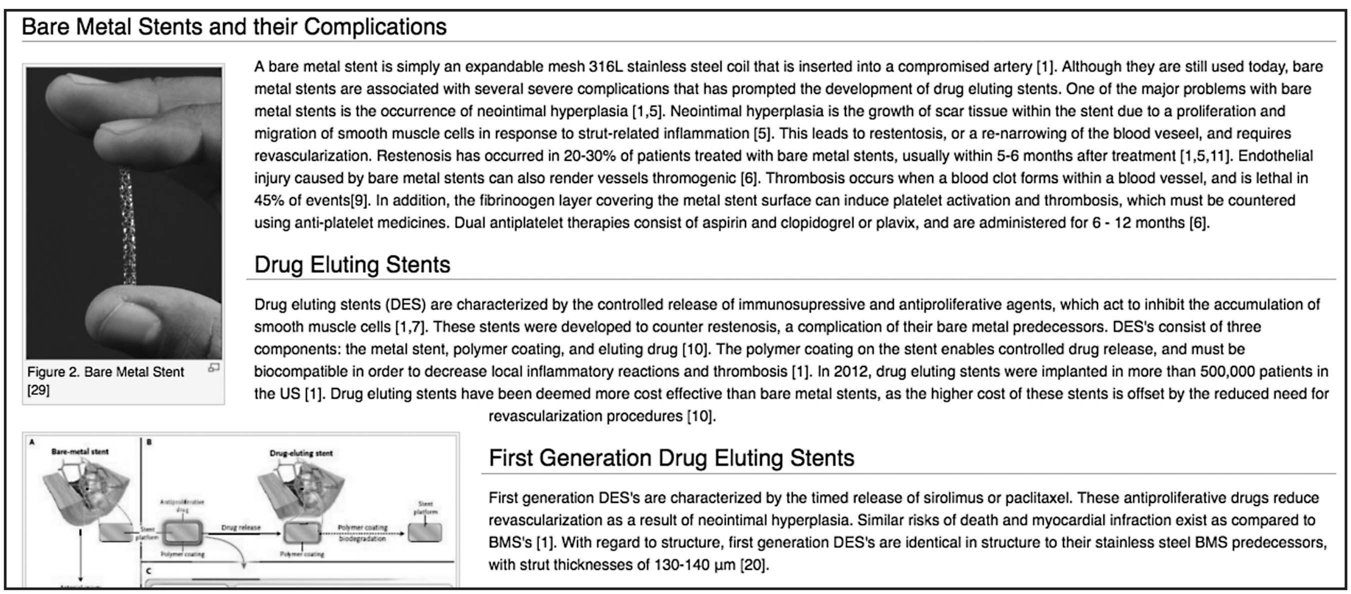
Chitosan is a naturally occurring cationic aminopolysaccharide which is obtained from the deacetylation of chitin, a carbohydrate based polymer. It is composed of N-acetylglucosamine and glucosamine, linked through a 1-4 glycosidic linker [1]. Chitosan' s main molecular chain is hydrophilic, but also possesses hydrophobic behavior due to the presence of N-acetyl groups. As a result; chitosan tends to form aggregates difficult to dissolve in neutral conditions. Because of the presence of amino groups, chitosan is a natural polyelectrolyte therefore it can easily dissolve in acidic conditions [6]. As a result, chitosan can be easily applied in pH sensitive drug delivery, especially in the treatment of cancer, since tumor sites are acidic. Chitosan adheres to mucosal surfaces and can penetrate tight junctions, which makes it an excellent drug-eluting polymer. [1]Chitosan has been successfully used to orally deliver insulin, which is usually digested by enzymes in the gut before it can make it to the bloodstream [6]. Chitosan can easily form micelles, via self assembly due to its hydrophobic and hydrophilic compositions. This characteristic enhances its use as a delivery polymer for hydrophobic drugs.

Hyaluronic Acid

Hyaluronic acid (hyaluronate) is a naturally occurring polysaccharide, present in the extracellular matrix in the human body. It is highly soluble and can be easily modified for drug delivery, especially through conjugation with drug molecules and proteins. Hyaluronate has a very high water retention capacity; as a result it is popularly used in skin regeneration therapy, and is available commercially in anti aging creams from companies such as instaNatural. Hyaluronate has been successfully used in the controlled, slow release of Vitamin E for wound healing. Hyaluronic acid is applied in the synthesis of the nanoparticle itself, together the cationic lipid dioctadecyldimethylammonium bromide (DODMA) and lecithin. Hyaluronic acid is also incorporated in the synthesis of the polymeric film that holds the suspended nanoparticles, together with aloe Vera extract.

Hyaluronate is negatively charged; therefore it binds to the polar head of lipids through attractive electrostatic interactions. The hydrophobic portions of lipids interact with the lipophilic vitamin E. This is how the core shell of most particles involving hyaluronate and lipids are formed [7].

Figure 2. *Excerpt from Wiki textbook page on "Drug-Eluting NanoPolymers." This page is taken from Chapter 4 of the Wiki textbook on Biomaterials. This author discusses creating nanoparticles from a variety of different polymer sources that can act as drug delivery vehicles.*



Bare Metal Stents and their Complications

A bare metal stent is simply an expandable mesh 316L stainless steel coil that is inserted into a compromised artery [1]. Although they are still used today, bare metal stents are associated with several severe complications that has prompted the development of drug eluting stents. One of the major problems with bare metal stents is the occurrence of neointimal hyperplasia [1,5]. Neointimal hyperplasia is the growth of scar tissue within the stent due to a proliferation and migration of smooth muscle cells in response to strut-related inflammation [5]. This leads to restentosis, or a re-narrowing of the blood veseel, and requires revascularization. Restenosis has occurred in 20-30% of patients treated with bare metal stents, usually within 5-6 months after treatment [1,5,11]. Endothelial injury caused by bare metal stents can also render vessels thromogenic [6]. Thrombosis occurs when a blood clot forms within a blood vessel, and is lethal in 45% of events[9]. In addition, the fibrinoogen layer covering the metal stent surface can induce platelet activation and thrombosis, which must be countered using anti-platelet medicines. Dual antiplatelet therapies consist of aspirin and clopidogrel or plavix, and are administered for 6 - 12 months [6].

Figure 2. Bare Metal Stent [29]

Drug Eluting Stents

Drug eluting stents (DES) are characterized by the controlled release of immunosupressive and antiproliferative agents, which act to inhibit the accumulation of smooth muscle cells [1,7]. These stents were developed to counter restenosis, a complication of their bare metal predecessors. DES's consist of three components: the metal stent, polymer coating, and eluting drug [10]. The polymer coating on the stent enables controlled drug release, and must be biocompatible in order to decrease local inflammatory reactions and thrombosis [1]. In 2012, drug eluting stents were implanted in more than 500,000 patients in the US [1]. Drug eluting stents have been deemed more cost effective than bare metal stents, as the higher cost of these stents is offset by the reduced need for revascularization procedures [10].

First Generation Drug Eluting Stents

First generation DES's are characterized by the timed release of sirolimus or paclitaxel. These antiproliferative drugs reduce revascularization as a result of neointimal hyperplasia. Similar risks of death and myocardial infraction exist as compared to BMS's [1]. With regard to structure, first generation DES's are identical in structure to their stainless steel BMS predecessors, with strut thicknesses of 130-140 µm [20].

Figure 3. *Excerpt from Wiki textbook page on "Stents." This page is taken from Chapter 6 of the Wiki textbook on Tissue Engineering in the Cardiovascular Sys tem. This page has been updated over three courses and improved over a student-driven, iterative process.*

interests and recent advancements in tissue engineering. Background topics include overviews of different types of stem cells, how cells adhere to biomaterials, the mechanics of materials and how cells respond to stiffness, imaging techniques, and an overview of materials used in tissue engineering (*e.g.*, poly(ethylene) glycol, poly(lactic) acid, titanium, ceramics, and spider silk). We have included three excerpts from these pages in Figures 1-3. Special interest topics abound, including tissue-engineered cartilage, stents, artificial hearts, the microbiome, and tissue engineered spleens, etc. We have chosen to organize these pages to make a textbook that flows from cells to biomaterials to applications. However, it is important to note that this flow can be easily adjusted and edited from year-to-year, due to the inherent flexibility and editable nature of the online Wiki textbook format.

Another possible variation on this approach would be to allow students to create/choose their own topic to add to the Wiki textbook. Within the context of our Tissue Engineering course this is not preferable, since many students have had minimal to no exposure to the necessary biology background to propose an appropriate topic. However, for other courses more closely related to the core chemical engineering discipline (*e.g.*, design, materials, energy, etc.), this is a potentially attractive approach. In our Tissue Engineering course, instead of exams, we give students a team research project due at the end of the semester. Students use the wiki textbook as a starting place for their research project. Previous iterations of the course had take-home exams, which also pulled from the textbook material, but we have since decided to emphasize teamwork and communication skills as priorities for this course.

For the new course on microfluidics, current and planned pages include introductory topics on various fabrication strategies such as soft lithography, micro-contact printing, microfluidic valves, paper microfluidics, and 3D printing, as well as general applications such as separations, purification, etc. The microfluidics course further incorporates special interest pages written by teams of students to present an overview of how microfluidic technologies have been used to address specific scientific challenges (*e.g.*, studying cancer metastasis). Here, the topics relate directly to a parallel hands-on design project where students build and test microfluidic devices to address a specific scientific need.

There are several features of the online Wiki format that are distinct from traditional textbooks. Importantly, the textbook is free, not only to students in the class, but also to anyone with internet access. Google Analytics can be used to track this dissemination, both by the number of independent visits (Figure 4) and from what region of the world a user is accessing the website. Furthermore, because students update the textbook every semester, it is essentially a living resource that can be edited as a field/topic continues to develop and mature. Finally, because the students are the authors of the textbook, they feel ownership of their project. This sentiment can increase their willingness to read required materials.

As part of an in-class assessment of the Wiki use in Tissue Engineering, we quantified how much time each individual student spent on crafting and refining their Wiki page (Figure 5). The average total time spent on making these pages was 19 hours for CHEM-ENG 575 for the spring of 2016. Immediately obvious from this data collation is that students spent the bulk of their time reading peer-reviewed papers on their topic. Interesting discrepancies arise between students that created pages on new topics or were updating an existing page. New pages took an average of 20 hours, existing pages an average of 16. Updated pages required less time on peer-reviewed literature and more time proofreading, likely because they needed to integrate their thoughts and unique perspective with a previous student's take on the topic.

ASSESSMENT AND DISSEMINATION

The students, by and large, were very positive about using and creating the Wiki pages as part of the textbook. During the 2016 offering of Tissue Engineering (CHEM-ENG 575), all of the students were polled. A full 100% of students used the Wiki textbook for reading, and over 75% of the class used the Wiki textbook for research on topics outside of their assigned readings. They also largely liked the online textbook compared to traditional textbook formats, stating that "Wiki pages are better to understand and cheap (free)," that "information was compressed and easier," that they found it "better to learn by contributing," and that the "Wiki is well-synthesized, with concise information and good jumping points." Drawbacks of this format the students noted included that the "Wiki pages are more prone to errors" than traditional textbooks, and that "textbooks are better because of appendices and indices." This last point is well taken, and this is a drawback of the wiki format. Creating an index for a living document is likely too time-consuming to be useful. Instead, the openwetware format automatically creates an index header, which is updated at every edit. For Tissue Engineering, we have turned this feature off as it can become very long, but shorter wiki textbooks could benefit from this feature.

Here are some excerpts from previous student surveys from the Tissue Engineering course (2012- 2015): "I liked the variety of topics covered in the Wiki presentations." "The Wikis seemed more tedious than useful." "The topics were very interesting. I learned a lot about biology and how to manipulate it. Wiki articles are a great way to add different information." "Interesting material and I loved the student Wikis." "I enjoy the Wiki pages, they provide opportunities for students to learn from peers." "I enjoyed how much this class was student run." "The Wikis were a good idea and I learned a lot by doing the research and presenting it."

Within a single semester, it is only possible to cover a finite number of Wiki topics. From year to year, Wiki topics can be repeated to keep the material updated, or, in some cases improve the coverage from a previous year. In this way, if a student does a below-average job on a topic, it can be improved in the following year. We have instructed students to add to the existing page and add their name to the author list. For a revised page, we typically request that the page have at least 50% new material to show they significantly contributed to the topic. Although not within a single year, this also gives the opportunity for students to assess and improve upon the work of previous students.

THE INTERSECTION OF WIKIS AND ABET

The integration of Wikis into the classroom represents an excellent opportunity to cover many aspects of the current ABET accreditation criteria. We suggest, broadly, that the use of Wikis ais relevant to the following ABET (a)-(k) criteria, with those areas covered strongly shown in bold. Of particular

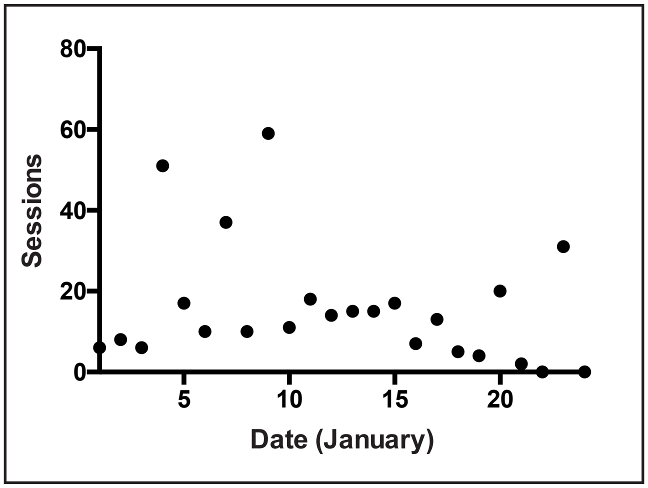


Figure 4. Tracking of website access over a representative month. Google Analytics showed that over the month of January, 2016, dozens of unique users accessed the Wiki textbook each day. As a reference, the first day of the course was Jan. 19, 2016.

note, many of the ABET criteria covered well by the Wiki exercise are those criteria which are often otherwise difficult to integrate into the core Chemical Engineering curriculum:

(b) Experiments: Although students do not directly perform experiments, they have to critically assess current literature in the field, which includes experimentation, during their wiki creation. Wiki creation forces students to analyze and interpret data from the peer-reviewed literature. These reported data and experimental procedures can then be leveraged in the design of hands-on experiments, as is implemented with the design and testing of related microfluidic devices in CHEMENG 590E.

(f) Professional & Ethical: Within tissue engineering, this is by necessity covered within Wikis. Wiki pages cover animal experimentation, clinical trials, FDA regulations, the boundaries and overlaps between science and the public, and the ethical issues of stem cells.

(g) Communication: Student creation of Wikis is intimately tied with communication in multiple ways. First, students have to distill dense scientific publications into a format that

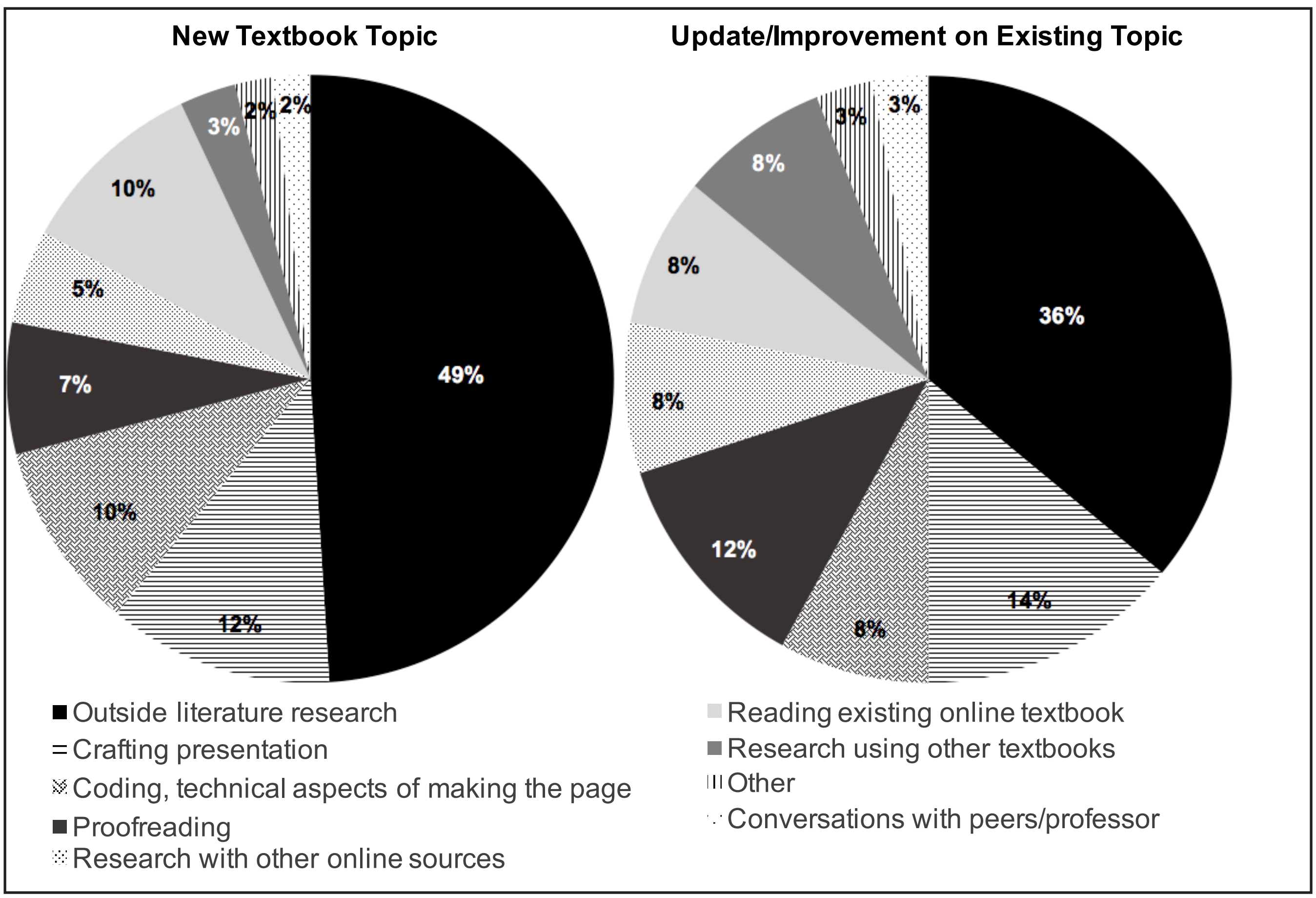


Figure 5. Time spent on textbook pages. Pie charts show how much time students spent on various aspects of the development of their Wiki pages, broken down by if they were new pages for the textbook (left) or updates of existing pages created in previous years (right). N=30 students surveyed in CHEM-ENG 575.

is understandable to them and the rest of the class when they create pages. This is a key skill for any burgeoning engineer. Our approach also ties each page to a class-lecture-style presentation by the author(s), which offers oral communication practice as well.

(h) Global/Societal Impact: Wikis are flexible, making it very easy to integrate these topics into the Wiki pages. We have found that students are keenly interested in tying their education to global contexts.

(i) Lifelong Learning: One of the most important things students learn during this wiki process is the power of internet editing and hosting information, essentially permanently. This process helps students as they encounter both trusted and untrusted sources throughout their lives, and how to critically assess peer-reviewed literature as they continue to learn long after they have left the university.

(j) Contemporary Issues: This is a key feature enabled by Wikis, to keep the textbook alive and editable, and therefore contemporary.

(k) Applications: Students typically gravitate toward literature related to their topic with an engineering slant, and many discuss the role of engineers (chemical and otherwise) in creating the technologies related to these Wikis. Wiki topics chosen could also cover specific technologies, such as atomic force microscopy (AFM) and ultrasound imaging in the case of tissue engineering, or the myriad technologies and applications in the field of microfluidics and microscale systems. As stated earlier, wiki topics by students follow an introductory lecture by the instructor. Since the wiki pages students choose are topical, they include the application of the general knowledge from the instructor lecture.

CONCLUSIONS AND AREAS FOR ADDITIONAL INNOVATION

Here, we suggest the use of Wiki textbooks for upper-level elective classes. While extending the use of Wiki textbooks to core chemical engineering classes is possible, undergraduate core courses do not typically suffer from the same challenges related to rapid content evolution, and thus having an editable textbook is less critical in more established core chemical engineering courses than in more rapidly developing topical courses. Furthermore, professors of core curriculum typically have very strong opinions of textbooks for those courses. Thus, while the issue of student engagement remains, textbook costs can be mitigated through the purchase of used textbooks. The implementation of Wikis has been reported for in a process control course.[22] However, their utility in this context was more to facilitate student communication, rather than a primary source of information. We propose that Wikis could be further used to highlight recent applications of the core curriculum, allow for the extension of topics into other fields, and provide descriptions of companies that use and apply core principles, etc. However, it is unlikely that Wikis would be used as the sole material reference for a course unless the Wiki were written and updated primarily by the instructor or graduate students.

One area for additional innovation in our Wiki textbook approach would be to incorporate student feedback into the textbook page-creation process. As it stands, our courses gather feedback from students on the individual presentations, but not on the Wiki pages created, where the instructor and TAs do all of the grading. Possible mechanisms to incorporate more peer review would be to (a) have the class evaluate the textbook during their assigned reading, and/or (b) allow a reasonable time period for peer review of the newly created/edited pages (*e.g.*, 1 week), and have classmates give suggestions for page improvements. Hohne, et al. recently described a similar process applied to the aforementioned process control course.[22]

In sum, we have found that Wiki textbooks are an excellent way to incentivise student engagement in learning topics ranging from Tissue Engineering to Microfluidics and Microscale Systems. Overall, students enjoyed creating the pages and learning about topics from their peers, as opposed to traditional lectures from the instructor. We expect to use these for many years to come for these courses, and we are hopeful to disseminate them more widely in the near future.

ACKNOWLEDGMENTS

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