An Open Online Resource for a Conservation Principles Course in Bioengineering

James Abraham, University of Illinois at Urbana - Champaign

James Abraham is a Master of Engineering student in Bioengineering at the University of Illinois at Urbana-Champaign, where he also earned his B.S. in Bioengineering.

Prof. Holly M Golecki, University of Illinois at Urbana - Champaign

Dr. Holly Golecki (she/her) is a Teaching Associate Professor in Bioengineering at the University of Illinois Urbana-Champaign and Department of Biomedical and Translational Sciences at the Carle-Illinois College of Medicine. Holly studies biomaterials and soft robotics and their applications in the university classroom, in research and in engaging future engineers in human-centered design. Holly received her BS/MS in Materials Science and Engineering from Drexel University and her PhD in Engineering Sciences (Bioengineering) from Harvard University.

Dr. Jennifer R Amos, University of Illinois at Urbana - Champaign

Dr Amos joined the Bioengineering Department at the University of Illinois in 2009 and is currently a Teaching Professor in Bioengineering.

Dr. Ali Ansari, University of Illinois at Urbana - Champaign

Ali Ansari is a Teaching Assistant Professor at the University of Illinois at Urbana-Champaign. He holds a Masters and Ph.D in Bioengineering from the University of Illinois at Urbana-Champaign, and graduated from Southern Methodist University with a degree in Electrical Engineering. Ali has been teaching for the past two years at Bucknell University in both the Biomedical Engineering and Electrical and Computer Engineering and been focusing on student focused pedagogy centered around Game-based learning techniques.

Shreya Gustafson

Shreya is an undergraduate student in the Department of Bioengineering at the University of Illinois at Urbana-Champaign.

Allison Ilene Lewis, University of Illinois at Urbana - Champaign

Allison is an undergraduate student in the Department of Bioengineering at the University of Illinois at Urbana-Champaign.

Yueyang Li, University of Illinois at Urbana - Champaign
Madison Christine Fanning, University of Illinois at Urbana - Champaign

Madison Fanning is an undergraduate student in the Departments of Bioengineering and Chemistry at the University of Illinois Urbana-Champaign.

Cooper Douglas Brown, University of Illinois at Urbana - Champaign
Prof. Caroline Cvetkovic, University of Illinois Urbana-Champaign

Caroline Cvetkovic is a Teaching Assistant Professor of Bioengineering at the University of Illinois Urbana-Champaign, where she instructs courses in quantitative physiology, neural engineering, biofabrication, and heat transfer. She earned her B.S., M.S., and Ph.D. in Bioengineering at the University of Illinois Urbana-Champaign. She then completed a postdoctoral fellowship in the Center for Neuroregeneration and Department of Neurosurgery at the Houston Methodist Research Institute.

An Open Online Resource for a Conservation Principles Course in Bioengineering

Abstract

Bioengineering (BIOE) programs lack a standardized curricular framework, which can hinder students' ability to transfer knowledge across courses and understand the broader context of their learning. Without a consistent scaffold, students may struggle to build an integrated understanding of core concepts or see how foundational learning connects to later applications. This issue is further exacerbated by the interdisciplinary nature and the lack of standardized bioengineering textbooks or terminology. Here, we describe "BIOEref," a dynamic, cross-referenced digital resource designed to streamline bioengineering curriculum pathways, standardize terminology, and embed interdisciplinary relevance into foundational engineering principles.

This paper details the development of BIOEref specifically for a core sophomore-level course in Conservation Principles at the University of Illinois Urbana-Champaign. The process involved identifying core classes with interconnected curriculum, reformatting existing content, and deploying pages through a Python-driven pipeline to a live website featuring concise technical content, interactive diagrams and animations. Unlike static resources, these pages synthesize instructor notes with relevant prerequisite content and link to existing reference pages across various fields, including mechanical engineering and electrical engineering, as well as the biological, chemical, and physical sciences.

The effectiveness of this resource is evaluated through a mixed-methods approach. Website usage analytics from Fall 2025 are analyzed to identify usage patterns, such as the increased engagement observed prior to homework deadlines, quizzes, and exams. Furthermore, we utilize Biggs' revised Two-Factor Study Process Questionnaire (R-SPQ-2F) to assess shifts in student motivation and "deep" versus "surface" learning strategies throughout the semester. The findings suggest that structured digital resources can play a vital role in supporting student navigation of complex engineering sequences. This work provides a template for other departments seeking to implement similar cross-course reference tools to enhance creativity and curricular continuity.

Introduction

Bioengineering and biomedical engineering (BIOE/BME) are interdisciplinary, multifaceted fields that require students to integrate concepts from multiple disciplines, including a working understanding of physical, biological, electrical, and data-driven systems [1]. Currently, the majority of BIOE courses do not have standardized systems for comparing and coordinating curriculum, thus limiting students' ability to transfer knowledge across courses and understand the broader context and applications of their learning [2]. This can also impact career paths in industry [3,4]. The problem is further exacerbated by the lack of comprehensive textbooks in this relatively new field, owing in part to the breadth of knowledge covered by the BIOE/BME curriculum. Moreover, traditional textbook usage has been declining, as students prefer concise, interactive formats to engage with the curriculum [5].

Given these challenges, a scalable reference system can provide great value to departments seeking curricular coherence and to students desiring contextual relevance. A consistent scaffold would enable students to build an integrated understanding of core concepts and demonstrate how foundational learning connects to later applications. The success of similar initiatives in established engineering fields offers a viable and implementable path forward as a translatable model. Implemented across multiple courses at the University of Illinois Urbana-Champaign (UIUC), the resource demonstrated short-format, interactive online content that significantly improved student engagement compared to traditional textbooks, which may be cost-prohibitive [5-9].

Inspired by this framework, we created BIOEref as a comprehensive online framework that translates foundational engineering principles into biological applications (**Appendix A**) [10]. Through its creation, we aim to establish consistent terminology and key concepts, streamline curriculum pathways through linked courses, and embed interdisciplinary relevance. BIOEref is dynamic and cross-referenced, helping students connect ideas across different disciplines (e.g. mechanical and electrical engineering, biological and physical sciences). Each course page will synthesize instructor notes, relevant prerequisite content, and link to existing reference pages for different fields where applicable.

Here, we detail the development and implementation of BIOEref for a sophomore-level Conservation Principles course (BIOE 201) as a case study. This course focuses on foundational topics necessary for any bioengineering program, such as accounting equations and conservation principles. Throughout the reference pages, cross-course connections are emphasized through in-text hyperlinks to related course topics and example problems summarizing covered material. Analytics describe the frequency of page usage throughout the Fall 2025 semester.

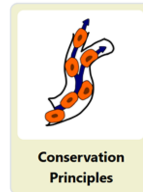
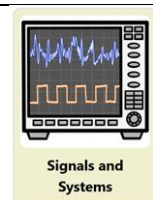
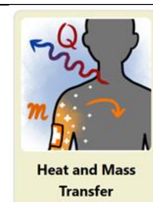
Additionally, we analyze pre- and post-term student data to investigate surface vs. deep learning approaches, strategies, and student motivation using the Biggs' Revised Two-Factor Study Process Questionnaire (R-SPQ-2F) [11,12]. This instrument classifies responses into two types of learning approaches, deep and surface, each comprising motive and strategy subscales. The deep learning approach is characterized by intrinsic motivation with a personal commitment to understanding the material by seeking logical connections, combining resources, and applying prior knowledge and experience [13,14]. In contrast, the surface approach reflects extrinsic pressure to study, difficulty in linking ideas, and vague perceptions of study strategies. These results offer preliminary insight into how deep learning is fostered through contextualized materials.

Methods

Course Descriptions

Five courses in the Bioengineering Department (**Table 1**) were identified as initial development sites. Four of the courses are foundational in the core undergraduate curriculum: Conservation Principles for Bioengineers (BIOE 201), Signals and Systems in Bioengineering (BIOE 205), Transport and Flow in Bioengineering (BIOE 360) [15], and Senior Design (BIOE 400) [16,17] Additionally, Introduction to Soft Robotics (BIOE 498) is an upper-level elective [18-20]. These courses are interconnected in the undergraduate sequence at UIUC.

Table 1. The team first identified the BIOE courses that would be included in the initial stages of the project and gathered relevant instructional materials.

Course / Level	Description	Connections to Other Courses	
BIOE 201: Conservation Principles for Bioengineers *2nd year, fall*	Brings together principles of general chemistry, physics, cellular biology, and calculus to solve problems at the interface of engineering and medicine. Includes conservation of energy, mass, and momentum. Introduces MATLAB as a problem-solving tool. *(Analyzed in this paper.)*		Course connections: 360
BIOE 205: Signals and Systems in Bioengineering *2nd year, spring*	Introduces concepts of signal and systems into how students see and analyze the world, especially applied to biological contexts such as electrical signals within the body. Major components include Laplace and Fourier transforms, transfer functions, convolution, and an introduction to Simulink and filtering.		
BIOE 360: Transport and Flow in Bioengineering *3rd year, spring*	Builds off the concepts of conservation principles to apply differential equation analysis towards solving fundamentals of heat transfer, fluid dynamics, and mass transport in the context and analysis of biological and bioengineered systems.		Pre-requisite: 201
BIOE 400: Senior Design *4th year, fall or spring*	Requires students to use skills from all prior courses into a capstone project in which teams solve design challenges for industry, clinical, and academic clients. Emphasizes engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.		Pre-requisite: 205 Course connections: 201, 205, 360, 498
BIOE 498: Introduction to Soft Robotics *Elective*	Applies fundamentals of polymer chemistry and sensors to understanding form and function of wearable devices and soft robots [19]. Students build actuators and sensors using polymer molding and fabrication techniques. This course leverages fundamental concepts from mechanical and electrical engineering applied in biomedical device design [18].		Course connections: 201, 205, 360

Page Development Workflow

As the first course in the sequence, Conservation Principles for Bioengineers (BIOE 201) was designated as the first for development. Relevant instructional materials included lecture notes, example problems, diagrams and other instructor-provided resources. These materials were then converted into an outline reflecting the structure of the course and became the foundation for the corresponding reference page. Using the course topic outline, the BIOE 201 content was transferred into the BIOEref page template, which was informed by the layout and organizational style of previously published reference pages. LaTeX drafts were converted into '.astro' files using a Python script, which allows for the pages to be easily integrated into the project's website framework. Diagrams and visual components were added during this step to improve the clarity and readability of the reference pages. Once converted, the pages were uploaded to the BIOEref website through GitHub, which served as the system for editing and coordinating team contributions to the collective reference page website (**Figure 1**).

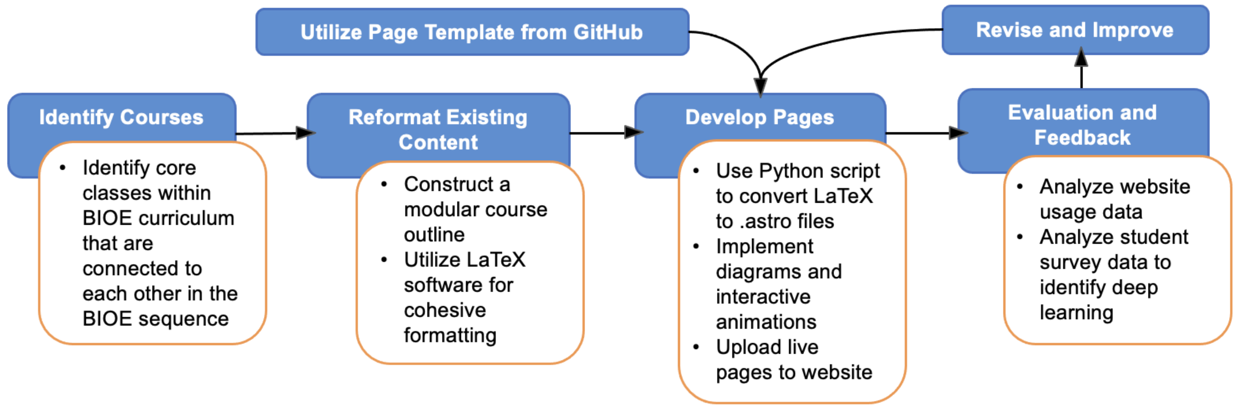


Figure 1. Creation of BIOEref followed a structured workflow meant to translate existing course content into reference page format.

Usage Analytics

Following initial publication of the BIOE 201 reference pages, the team evaluated their usage by analyzing website traffic patterns and views using Google Analytics. Reviewing student feedback also provided significant insight into how they interacted with the materials and how the pages supported student learning. Usage analytics for the semester were sampled daily, while data from quiz and exam weeks were sampled hourly to more closely examine the relationship between critical course deadlines and website traffic. Moreover, the individual pages were tracked separately to examine how viewership and active users shifted in response to course curriculum progression.

Evaluation with the Revised Study Process Questionnaire

Students (n = ~100 total) were offered an opportunity to take the Biggs' Revised Two-Factor Study Process Questionnaire (R-SPQ-2F) [11,12] at pre- and post- timepoints during the study, at weeks 2 ("early semester"; n = 49 responses) and 15 ("late semester"; after the last exam; n = 22 responses). The R-SPQ-2F consists of 20 items on a scale ranging from "always or almost always true of me" to "never or only rarely true of me" (see **Appendix**). The SPQ survey measures approaches to learning by assessing their motives and strategies and characterizing them as "deep" or "surface": DM = Deep Motive, DS = Deep Strategy, SM = Surface Motive, SS = Surface Strategy (subscales). D = Deep Approach and S = Surface Approach (main scales). Each subscale has 5 items for a total of 10 items per study approach (**Figure 2**).

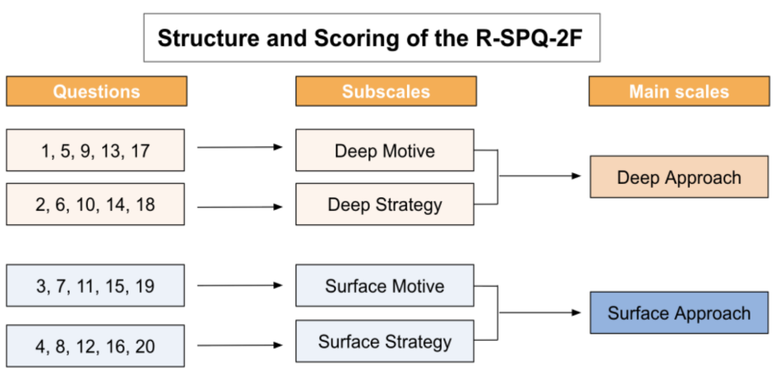


Figure 2. Structure of the Revised Two-Factor Study Process Questionnaire (R-SPQ-2F), showing which questionnaire items contribute to each subscale and main scale (see **Appendix**).

Additionally, in week 6 (immediately following Exam 1), students were provided with an opportunity to provide informal early feedback on the course. In addition to general questions about the course and instructor, students were asked about their time spent studying for the course and what resources they used when studying. In week 15, in addition to the R-SPQ-2F questions, students were categorized into those who self-identified as BIOEref "Users" (n = 12) or "Non-Users" (n = 10). Furthermore, they were grouped according to whether their use of the pages increased, decreased, or stayed the same during the semester. We also provided an opportunity for open-ended feedback.

Data from the R-SPQ-2F were treated as ordinal and non-parametric. Non-paired groups (early vs. late timepoints; Users vs. Non-Users) were compared independently using a Mann-Whitney U test to assess changes in approach and motive in response to using BIOEref. For multiple comparisons, alpha values were corrected based on the number of comparisons. Analyses were completed with IBM SPSS Statistics. This study was approved by the Institutional Review Board at UIUC as Non-Human Subject Research (Project IRB25-1094).

Results and Discussion

Conservation Principles Reference Pages

BIOE 201 is a foundational course for how to identify, formulate, and solve complex problems. This course covers topics of energy conservation, as well as an introduction to transport, heat, statics, and fluid mechanics. Specific topics are detailed in **Table 2**.

Table 2: BIOE 201: Conservation Principles course outline translated into reference pages and corresponding topics.

Page	Topics	Page	Topics
Introduction to Variables and Properties (Week 1)	• Variables, Units, Dimensions • Extensive and Intensive Properties • Scalar and Vector Properties	*Conservation of Mass (Weeks 2-5)*	• Overview: Types of Mass • Conservation Statements → Algebraic, Differential, Integral • Multicomponent Mixtures • Systems with Chemical Reactions
Conservation & Accounting Laws (Week 2)	• Conceptual Framework for Accounting • Process to use Accounting Equations • Forms of Accounting Equations → Algebraic, Differential, Integral • Accumulation	*Conservation of Energy (Weeks 6-9)*	• Overview: Types of Energy → Potential Energy, Kinetic Energy, Heat and Work • Conservation Statements • Enthalpy • Systems with Chemical Reactions • Dynamic Systems
Problem-Solving Approaches	• Problem-Solving Process → Assemble, Analyze, Calculate, Finalize	*Conservation of Momentum (Weeks 10-14)*	• Overview: Types of Momentum • Conservation Statements • Linear Momentum, Angular Momentum • Rigid Body Statics • Fluid Statics

Across the pages, text is accompanied by figures, equations with derivations, callout boxes with reminders and warnings, and example problems with solutions (**Figure 3**).

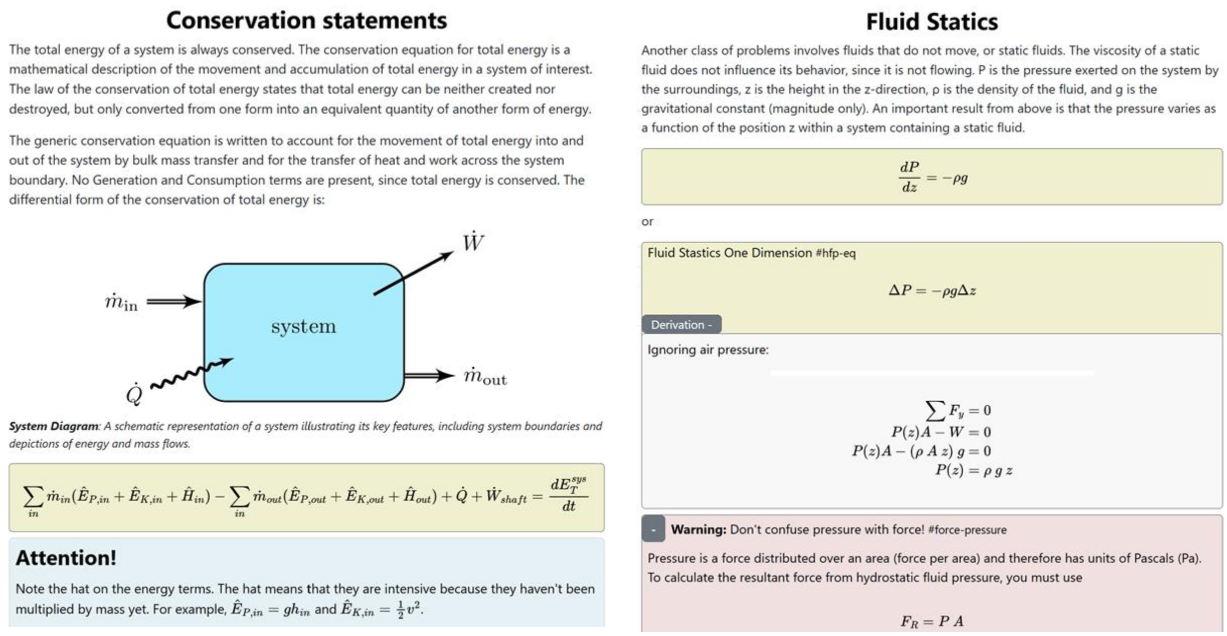


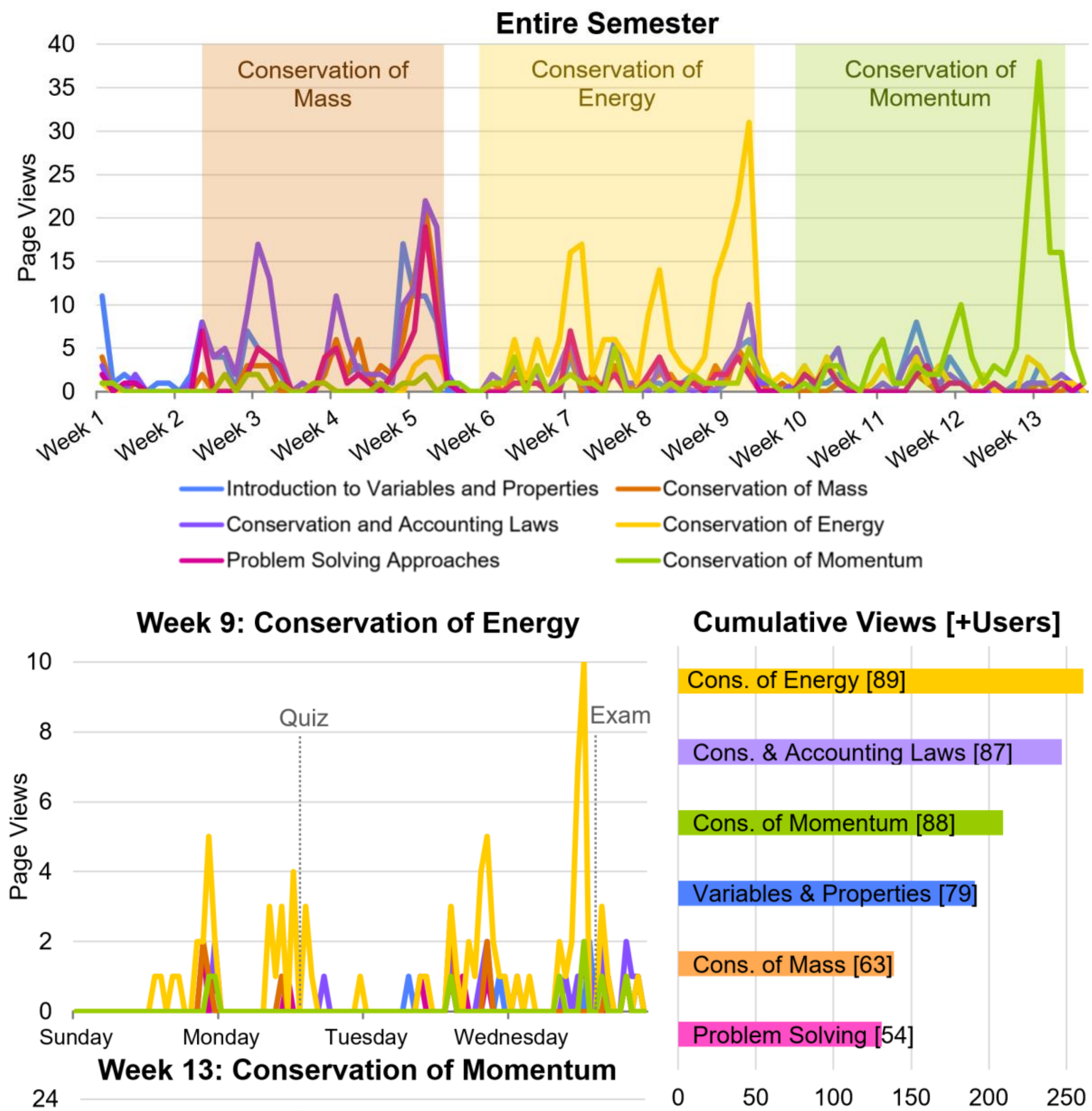
Figure 3: Example pages from BIOE 201. *Left*: Conservation of Energy page. *Right*: Conservation of Momentum page, featuring a derivation and warning.

Informal Early Feedback was collected in Week 6, after the first exam. In response to a survey asking *Which course resources have you used?*, 33% mentioned BIOEref at that time (behind past midterms and solutions, posted course notes, supplemental practice problems, and office hours, but ahead of lecture recordings, other online resources, and discussion boards).

Page Analytics

Complementary findings from a 2025 usage analysis of BIOEref had revealed high engagement when reference systems were centralized and contextually linked [5]. During both the Conservation of Energy and Momentum units of BIOE 201 (i.e., the second and third exam content), we observed that their respective pages were the highest viewed of BIOEref, showing a strong correlation between the relevance of the reference pages to the current course content (**Figure 4**). A slightly different trend can be observed in the first third of the semester, where four different introductory pages competed for the highest viewership. The Conservation of Mass page competed with three other introductory pages (Introduction to Variables and Properties, Conservation and Accounting Laws, Problem Solving Approaches) that established the problem-solving methodology used later throughout the course. Their traffic was elevated in the first unit but subsided as the course progressed and occasionally spiked around in-class quiz or exam days, suggesting that students saw the reference pages as a valuable resource to review class content.

Total website viewership increased with each progressive unit in the course (e.g., Conservation of Mass, Energy, and Momentum, sequentially). Active viewers ranged from 54-87 in the introductory pages to 63-89 in the conceptual units, out of a class of ~100. BIOE 201 is the first core course in the undergraduate sequence, possibly presenting a new challenge to students' organizational and study skills. Students may not yet know how to utilize various resources outside of (or in conjunction with) textbooks, lecture notes, and other course materials. With the development of new reference pages for other courses in the future beyond this pilot (**Table 1**), we anticipate increased users.



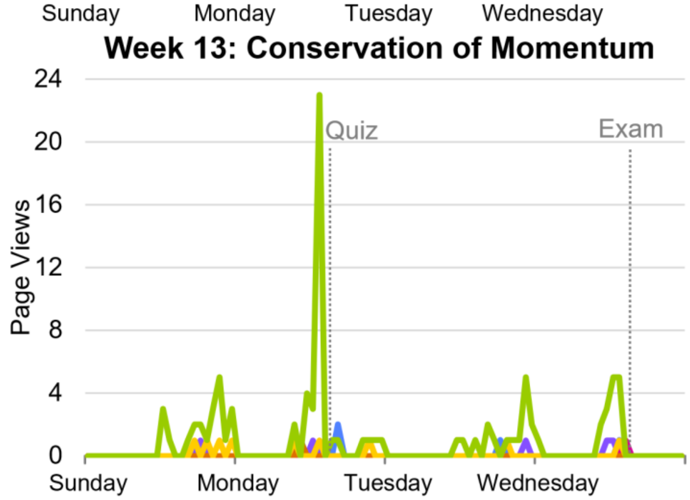


Figure 4: Website page analytics data. *Top*: individual page traffic throughout the semester, sampled daily. *Mid left*: page traffic surrounding Quiz/Exam 2, sampled hourly. *Bottom left*: page traffic surrounding Quiz/Exam 3, sampled hourly. *Bottom right*: cumulative views of each page throughout the semester, with [active users] noted for each page.

Examination of Deep vs. Surface Learning
Analysis of the students' responses to the R-SPQ-2F at "early" (n = 49) and "late" (n = 22) timepoints in the semester examined changes in overall deep (D) and surface (S) approaches (i.e., main scales) and deep vs. surface motives and strategies (i.e., subscales). Main scales were calculated as the sums of subscales (see **Figure 2**).

At the beginning of the semester (i.e., "Early"), overall deep approach (D) scored significantly higher than overall surface approach (S) ($p < 0.001$ with medium effect size; **Figure 5, Appendix B,C**). At this timepoint, individual subscales scored significantly higher in deep strategy (DS) vs. surface strategy (SS; $p < 0.001$ with medium effect size), and mildly higher in deep motive (DM) vs. surface motive (SM; $p = 0.85$) (**Appendix B,D**).

At the end of the semester (i.e., "Late"), we noted that D still scored higher than S ($p = 0.16$), but only with regards to students' motives (DM > SM; $p = 0.17$), not strategies (**Appendix B,C**). Regarding strategies, we observed an increase in surface vs. deep strategies (SS > DS; $p < 0.001$ with a large effect size; **Appendix D**). Interestingly, this relationship reversed from that in the early semester, possibly due to students' increased workload and number of final exams.

In a similar manner, from early to late semester, D decreased over time ($p = 0.15$) while S increased over time ($p = 0.3$). DM and DS ($p = 0.07$) were both higher earlier. SM stayed consistent while SS increased (**Appendix D**). Looking at individual questions from the R-SPQ-2F [10,11] over time (**Appendix E**), significant decreases were only observed in DS question *Q14 (DS): I spend a lot of my free time finding out more about interesting topics which have been discussed in different classes* ($p = 0.005$). A larger decrease was also noted in *Q5 (DS): I*

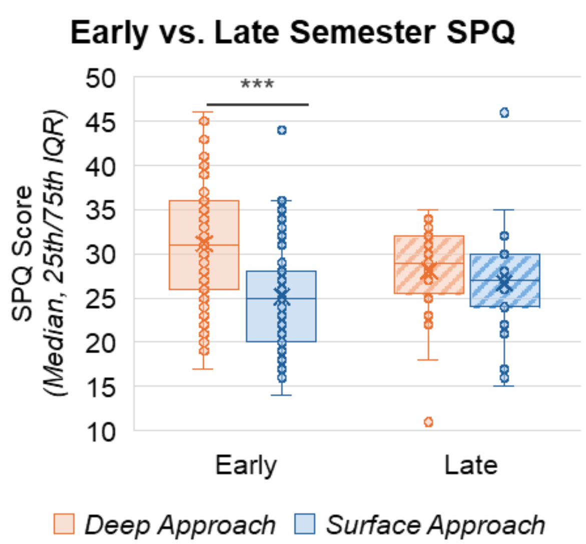


Figure 5: SPQ scores indicating changes in Deep Approach (D; orange) and Surface Approach (S; blue) scales between early (solid; n = 49) and late (patterned; n = 22) points in the semester. Significant differences are denoted for D vs. S (*** = $p \leq 0.001$). Boxes represent 25th/75th interquartile ranges and medians. "x" denotes the mean value; dots are individual data points.

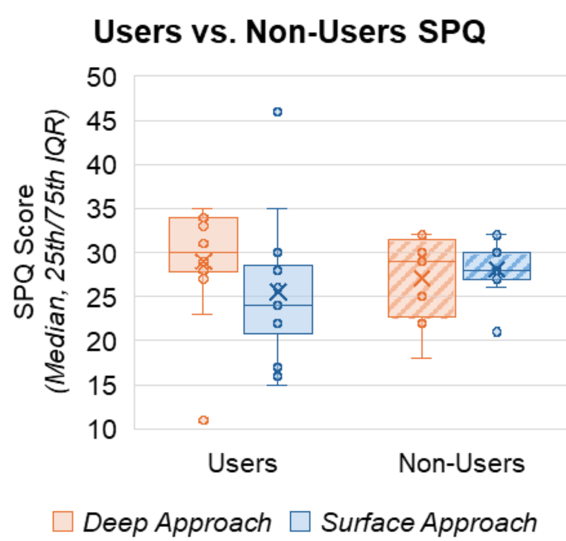


Figure 6: SPQ scores indicating changes in Deep (orange) and Surface (blue) Approach scales between students who identified as Users (solid; n = 12) and Non-Users (patterned; n = 10). Boxes represent 25th/75th interquartile ranges and medians. "x" denotes the mean value; dots are individual data points.

feel that virtually any topic can be highly interesting once I get into it ($p = 0.06$). The largest difference in favor of SM was found in *Q15: I find it is not helpful to study topics in depth. It confuses and wastes time, when all you need is a passing acquaintance with topics*, which increased throughout the semester ($p = 0.08$). No differences between user groups were observed in *Q19 (SM): I see no point in learning material which is not likely to be in the examination.*

We next analyzed usage patterns of "Users" ($n = 12$) or "Non-Users" ($n = 10$) of BIOEref throughout the course. Analysis showed that students who self-identified as Users by choice during the semester had higher scores for deep learning approach (D) and therefore lower scores for surface learning approach (S) than peers who did not use BIOEref, i.e., Non-Users (**Figure 6, Appendix F,G**). This was evident specifically in their motives and strategies; DM and DS were higher for Users than SM and SS, respectively (**Appendix H**).

When teasing apart individual study process questions for these groups (**Appendix I**), the largest differences in SPQ scores were calculated in favor of Users for DM questions *Q9 (DM): I find that studying academic topics can at times be as exciting as a good novel or movie* ($p = 0.059$, medium effect size) and *Q13 (DM): I work hard at my studies because I find the material interesting* ($p = 0.18$, medium effect size), compared to Non-Users. In contrast, the largest differences were calculated in favor of Non-Users for SS questions *Q8 (SS): I learn some things by rote, going over and over them until I know them by heart even if I do not understand them* ($p = 0.014$, medium effect size) and *Q20 (SS): I find the best way to pass examinations is to try to remember answers to likely questions* ($p = 0.014$, medium effect size), compared to Users. No differences between user groups were observed in *Q10 (DS): I test myself on important topics until I understand them completely, Q14 (DS): I spend a lot of my free time finding out more about interesting topics which have been discussed in different classes,* and *Q18 (DS): I make a point of looking at most of the suggested readings that go with the lectures.*

Average User SPQ scores also displayed more variability. Thus, at the late timepoint, we compared students who self-identified their BIOEref usage over the course of the semester as increased, consistent, reduced, or none. Those who increased their usage ($n = 5$) or remained consistent ($n = 5$) saw higher median D scores, compared to those who decreased usage ($n = 2$) or did not use BIOEref at all ($n = 10$), for whom DM outweighed SM, but SS dominated versus DS (**Appendix J**). Among students who increased their usage, DM and DS questions yielded the highest average scores. Among students who reported decreased usage or not using BIOEref, questions in SM and SS had higher average scores. Overall, though sample sizes were small at the end of the semester, examination of these user groups provides insight into how this resource can help to foster learning that trends towards a deeper approach.

According to Biggs, students who adopted surface learning (reflecting extrinsic pressure) focused on the substantive information and emphasized rote learning and memorization techniques. Research indicates that students who adopt a deep approach (characterized by intrinsic motivation) tend to be more motivated and engaged than those using a surface approach. Moreover, they demonstrate stronger critical thinking and analytical skills related to the subject matter [12]. Many factors influence student approaches to studying and using course materials. However, motivation to learn deeply versus developing a surface-level understanding is often driven by assessments that necessitate learning the concept or skill [21]. The goal of studying for surface learners could be to avoid failure in the examination. As they neglected to grasp and understand the key concepts of the subject, they consequently failed to apply the information in other circumstances [13,14]. In contrast, students using ‘deep-level processing’ focused not only on substance but also on the underlying meaning of the information [22].

The most likely explanation for our results showing a surface motive shift near the end of the semester aligns with a concept defined by Biggs as “constructive alignment,” which describes how students’ motivation may shift due to the structure of assessments in a course [23]. Several other STEM studies found that as the semester progressed, students perceived a greater workload or more pressure, which led to greater surface motives at the end of the semester [24,25]. Other studies have shown that the focus on needing to ‘make the grade’ at the end of the semester may override intentions to understand deeply and thus revert motives to more surface based [24].

Development Team Reflections

The BIOEref project team included course instructors from each participating course, a graduate teaching assistant, and three undergraduate students. The students were involved in different stages of the Bioengineering curriculum, which allowed for the presentation of complementary perspectives (**Table 3**). One was currently enrolled in BIOE 201 and provided input from an active student’s perspective. The remainder had completed multiple of the selected bioengineering courses. Faculty provided objectives for the course reference pages and reviewed for technical accuracy of course content, while students contributed to the organizational decisions and assembly of the reference pages. The structure of the team allowed each page to reflect the necessary subject matter while utilizing first-hand experience to address student learning needs in a natural way. Since the reference pages are intended to supplement or in some cases replace traditional textbooks, instructor notes, or other resources, it can be expected that their development will take time and effort. We also collected reflections from members of the development team to understand practical opportunities and challenges in implementing the pages in BIOE courses (**Table 4**).

Table 3. Student team member experiences. “U” = undergraduate; “G” = graduate student; “x” = student has taken the course; “TA” = student has been a Teaching Assistant for the course.

	Bioengineering Course Number				
Student	**201**	**205**	**360**	**400**	**498**
A (U)	x				
B (U)	x	x	x		
C (U)	x	x	x		x
D (G)	x	x	x (U) TA (G)	x (U) x (G)	

Notably, the team observed a sizable drop-off in response rate between early and late semester surveys. This may be attributed to the fact that participation in surveys was voluntary and that no extrinsic rewards were offered. Additionally, as students typically have increased assignments, responsibilities, and exams later in the semester, their willingness to participate in optional class surveys may decrease. As student identities were not tracked, it cannot be said whether there was any difference between late semester survey responders and non-responders.

Table 4. Faculty and student development team reflections by group, organized into themes, on building BIOEref. [X] indicates the specific student as coded in Table 3.

Theme	Faculty on Team	Students on Team
Perceived value for engineering courses (teaching or enrolled in)	• "Having a 'one stop shop' for all course content will improve continuity of design work and guidance." • "I am looking forward to the opportunity to collaborate more with the other instructors of courses in the sequence."	• Convenient source of equations and concepts with confidence that it is formatted for use in the course. [B] • Useful to have a simplified version of a textbook that is potentially more interactive [D] • Interested in the connection with other engineering departments [D] • "Being able to see the full course structure in one place helps me understand the purpose of each individual lecture/topic." [D] • "Centered my focus on new learning strategies for challenging topics." [A]
Easy aspects of page development	• Dedicated team members • Inspiration from other pages • "Once I started, it was fun and relaxing to assemble the pages."	• Familiarization with workflow and framework [A] • Navigating the Github and creating/assembling new pages ("assuming there is a template to follow") [B, D]
Challenging aspects of page development	• Getting started • Finding dedicated time • Understanding the workflow • Transitioning and improving existing course content • Effort required to revise content before going live on a page • Continual page improvement during and after the course • Securing support for continuous maintenance (from undergraduate support to Teaching Assistants of the course to faculty summer support, or some combination)	• Challenging to distinguish personal bias from general student feedback on desired page appearance [A] • Specific formatting for images and text takes some time to familiarize [B] • "[The conversion from] LaTeX is a black box process and difficult to troubleshoot if something goes wrong. Easier to start with HTML." [B] • "Understanding the Github workflow and how to use components present [would] have taken a long time without other courses' [pages] serving as templates." [D] • "I'm not the final authority on content; instructor review is preferred to ensure important information is accurate, present, and formatted." [B]
Opportunity to be creative	• "Creating visualizations for the pages was a fun, creative outlet." • "I enjoyed thinking of new and different ways to present the material, whether in text, images, or videos."	• "Ability to present complex topics in a digestible format" [A] • "Thinking of resources I wished to have when taking the courses and creating them in the reference pages." [B] • "Fun to think of different ways of presenting information to help [students] understand an otherwise complicated topic." [D]

Feedback from External Instructors

At the Biomedical Engineering Society's Annual Meeting in Fall 2025, BIOE/BME instructors external to the University of Illinois were asked to complete a survey after viewing a poster describing the BIOEref development process and reviewing the website content. The feedback is detailed in **Table 5**. These data will allow our team to think more globally about the development of future pages while forming collaborations within and across institutions.

Table 5. Feedback from other BIOE faculty, collected at BMES (n = 6).

What is your role?	• Instructor (n = 2) • Teaching track faculty (n = 1) • Postdoctoral fellow (n = 1)	• Graduate student (TA; n = 1) • Other (n = 1)
How likely would you be…	• to *use* reference pages in your courses? (4.17 ± 0.7) *(1 = very unlikely; … 3 = neither likely or unlikely; … 5 = very likely)*	• to *implement* reference pages in your courses? (4.33 ± 0.8)
Overall strengths	• Consistency across instructor and semesters	• Accessible, interactive • More easily digestible
Helpful features	• Images (n = 6) • Examples (n = 6) • Derivations (n = 4)	• Layout (n = 2) • Other (n = 1) *(e.g. videos)*
Suggestions for improvement	• Improved site layout and navigation • More functionality, interactivity	• Links to external references to better explain concepts
Courses most benefitted	• Introductory courses (n = 2) • Signals and systems (n = 1) • Design (n = 1) • Other (n = 2) *(e.g. Biomechanics, Instrumentation, Physiology, Tissue Engineering, Controls)*	• "Probably all of the above" • "I would prioritize classes that don't have as good of textbooks available (e.g., design over physiology)"

Future Directions

Pages are currently under development for four additional courses in the bioengineering undergraduate curriculum: Signals and Systems, Transport and Flow, Senior Design, and Introduction to Soft Robotics (see **Table 1**). Building on the development and use of BIOEref, this effort may also help connect concepts across the college of engineering, as students from many engineering disciplines connect their work to applications in BIOE. Additionally, implementing reference pages for other courses such as labs [26-28] could help to connect conceptual material with experimental outcomes. As BIOEref grows, longitudinal studies of these impacts on learning strategies and approaches will be conducted.

Developed reference materials can also be linked to the entrepreneurial mindset (EM) as outlined in the KEEN framework [29]. Preliminary analysis from comparable reference systems in introductory engineering courses demonstrated alignment between the reference pages and the KEEN framework [30] and revealed that student perceptions of the 3Cs (i.e., curiosity, connections, and creating value) improved most significantly in courses that featured animated and interdisciplinary pages [5]. Specifically, students identified real-world applications four times more often by the semester end, indicating that conceptual connections, when presented visually and contextually, can deepen curiosity and engagement. The tenets of the 3Cs can be related by incorporating healthcare and biological applications that expose students to fundamentals of bioengineering used to solve complex problems. Moreover, BIOEref itself has unique features that can further enhance the alignment with the 3Cs. We have mapped specific examples of how KEEN's Entrepreneurial Mindset and 3Cs can be incorporated into future course reference pages to increase the value of the pages for students (**Table 6)**. The open-source structure of BIOEref supports adaptation by other programs and institutions who are seeking

Table 6: Example alignment of BIOEref pages with 3Cs of KEEN's EM framework.

Curiosity	… for careers	Bioengineering students seek a wide variety of careers (in research, medicine, law, consulting, pharmaceuticals, the medical device industry, and more). "Did You Know?" sections can include information about how course concepts are used in industry, or link to videos for further exploration. Bioengineering students are motivated by learning about career options related to class through podcasts and other interview types [31].
Connection	… among BIOE courses	To date, there is limited connection among BIOE core courses. This project enables instructors of core courses to create formal threads and connections for students throughout the curriculum.
	… to prerequisite courses	Students struggle with content transfer [32]. Cohesive pages will help students to look back to prerequisite course content with specific links to increase knowledge transfer across undergraduate education. This can formalize our previously assembled resources while linking to shared pre-requisites for some fundamental concepts (e.g., from physics, biology, chemistry, math, or computer science).
	… to other disciplines	Bioengineering draws on other fields for fundamental concepts [1]. BIOEref pages create an opportunity to formalize previously assembled resources while linking to other engineering discipline-specific pages from mechanical, electrical, and materials engineering. (BIOE 201/360 students can benefit from references to thermodynamics; BIOE 205 links to core electrical engineering topics; and BIOE 400/498 points students to solid mechanics and prototyping pages.)
Creating value	… for students	Students desire to know why they are learning course concepts. "Heads Up" sections will help students understand where concepts will be used next. "Did You Know?" sections will point students to how these concepts are used in industry.

curricular unity and entrepreneurial engagement and thus has the potential to become an accessible resource that strengthens other bioengineering programs.

Conclusions

BIOEref addresses a gap in BIOE/BME education by establishing a structured and interconnected framework across core courses. With their development, we aim to provide consistency within our Bioengineering department while also developing a framework that could be adapted by other programs with varying curricula. The reality of college teaching is that instructors regularly and necessarily change, and therefore consistent notations and nomenclature demonstrate a constant throughline of variables, concepts, and formatting that maintains coherence despite these unavoidable changes.

In this paper, we documented the development and implementation of BIOEref using a Conservation Principles course as a case study for page development, student usage data, an examination of deep versus surface learning approaches, and development team dynamics. Our pilot implementation and evaluation of this resource for a Conservation Principles course is encouraging. Page usage increased for each relevant assessment (see **Figure 4**). Additionally, our analysis of student learning strategies during a semester where BIOEref pages were an advertised resource provides data that will help our team develop pages and assess their use. While further testing and evaluation of BIOEref is required to draw conclusions from this work, we will continue to monitor the R-SPQ-2 items and propose supplemental measures to Bigg's Revised Study Process Questionnaire [12].

Reflections from faculty and students on the development team are largely positive as well, as they see the value of these resources. Protected time for development is the biggest factor in bringing this resource online. Once pages are developed, we anticipate their maintenance to be minimal and include minor corrections, updating examples, or improving clarity. As with other resources like learning management sites or class presentations, it will be up to individual faculty to determine when and how to update this resource. Continuous maintenance is also important and may be managed in real time by Graduate Teaching Assistants or Undergraduate Course Assistants in a course support role. As development of the pages continues, we aim to reduce barriers for faculty to implement similar efforts at their institutions toward standardizing BIOE/BME curricula.

Lastly, we anticipate that expanded usage of BIOEref will facilitate greater cohesion and contextual relevance in BIOE. By showing students where reinforcement and reiteration occur for each concept, instructors can point to prerequisite classes where students may have learned the material, provide "just-in-time" skills needed for design or capstone courses [33], or prepare students for future classes where they will use this concept again. Finally, new sections could also highlight the relevance of course material to research, clinical practice, and industry.

Acknowledgements

The authors would like to thank The Grainger College of Engineering's Strategic Instructional Innovations Program (SIIP), the Kern Family Foundation, and the Department of Bioengineering for supporting this work. We would also like to acknowledge the feedback from students and the assistance provided by the MechRef team at Illinois.

References

[1] Citron, P., & Nerem, R. M. (2004). Bioengineering: 25 years of progress—but still only a beginning. *Technology in Society*, 26(2-3), 415-431.
[2] Gatchell, D. W., & Linsenmeier, R. A. (2014). Similarities and Differences in Undergraduate Biomedical Engineering Curricula in the United States. Paper presented at 2014 ASEE Annual Conference & Exposition, Indianapolis, Indiana. 10.18260/1-2--23015
[3] Boyd, L., Bradley, J., Gray, M. et al. (2025). Enhancing Biomedical Engineering Education Through Curricular Innovation: Developing Industry-Ready Engineers. *Biomedical Engineering Education*, 5, 155–161. 10.1007/s43683-025-00171-z
[4] Scott, R. A., Frickenstein, A. N., & Wilhelm, S. (2024). Longitudinal Analysis of Strategies for Improving Biomedical Engineering Student Knowledge of Career Paths and Desired Skillsets. Paper presented at 2024 ASEE Annual Conference & Exposition, Portland, Oregon. 10.18260/1-2--47751
[5] Raymond-Bertrand, J., Hoyle, M. R., Opolz, M. D., Admal, N. C., Chang, W. L., Golecki, T., Halloran, K. M., Luetkemeyer, C., Mercer, B., West, M., & Kersh, M. (2025). TL;DR Students don't read textbooks: designing online reference pages to enhance student learning. Paper presented at 2025 ASEE Annual Conference & Exposition, Montreal, Quebec, Canada. 10.18260/1-2--57291

[6] Chang, W. L., Hoyle, M. R., Opolz, M. D., Raymond-Bertrand, J., Admal, N. C., Golecki, T., Halloran, K. M., Hutchens, S., Luetkemeyer, C., Mercer, B., West, M., & Kersh, M. (2025). Reflecting on Ten Years of Building a Community of Practice for Teaching Innovations in Fundamental Mechanics Courses. Paper presented at 2025 ASEE Annual Conference & Exposition, Montreal, Quebec, Canada. 10.18260/1-2--57112

[7] West, M., & Herman, G. L. (2014). Sustainable reform of "introductory dynamics" driven by a community of practice. Paper presented at 2014 ASEE Annual Conference & Exposition, Indianapolis, Indiana. 10.18260/1-2–23081

[8] Jenkins, J. J., Sanchez, L. A., Schraedley, M. A. K., Hannans, J., Navick, N., & Young, J. (2020). "Textbook Broke: Textbook Affordability as a Social Justice Issue," *Journal of Interactive Media in Education*. 10.5334/jime.549

[9]https://open.spotify.com/episode/5WQHPjvShxf9ls8PQE8ka7?go=1&sp_cid=a1b5d8556de4b57411efec5cd9c7ca3e&utm_source=embed_player_p&utm_medium=desktop&si=zvLJPJEwS9eY3xWoDN3Vjg&nd=1&dlsi=c8988c6204d54933

[10] https://bioe.refpages.org/

[11] Biggs, J., et al. "Revised two-factor study processes questionnaire." PsycTESTS Dataset, 2001. 10.1037/t88352-000

[12] Biggs, J., Kember, D., & Leung, D. Y. (2001). The revised two-factor study process questionnaire: R-SPQ-2F. *British Journal of Educational Psychology*, 71(1), 133-149.

[13] Nelson Laird, T. F., Shoup, R., & Kuh, G. D. (2005). Deep learning and college outcomes: Do fields of study differ? Paper presented at the Annual Meeting of the Association for Institutional Research, San Diego, California.

[14] Nelson Laird, T. F., Shoup, R., Kuh, G. D., & Schwarz, M. J. (2008). The effects of discipline on deep approaches to student learning and college outcomes. *Research in Higher Education*, 49, 469-494.

[15] Cvetkovic, C., Meece, S., & Patnaik, T. (2025). Work in Progress: Using Student Reflection and Focus Groups to Improve an Undergraduate Bioengineering Transport Course. Paper presented at 2025 American Society for Engineering Education (ASEE) Illinois-Indiana Section Conference, Terre Haute, Indiana.

[16] Golecki, H. M., Amos, J. R., & Bradley, J. (2023). Designing Capstone Experiences for Interdisciplinarity in Biomedical Engineering Education. Paper presented at 2023 ASEE Annual Conference & Exposition, Baltimore, Maryland. 10.18260/1-2—42977

[17] Golecki, H. M., & Bradley, J. (2024). Experiential Learning: Exploring Nuances When Making Ethical Decisions in a Capstone Design Course. *Biomedical Engineering Education*, 4, 163–170. 10.1007/s43683-023-00126-2

[18] Golecki, H. M., Robinson, J., Cvetkovic, C., & Walsh, C. (2024). Empowering Students in Medical Device Design: An Interdisciplinary Soft Robotics Course. *Biomedical Engineering Education*, 4, 399–408. 10.1007/s43683-024-00143-9

[19] Golecki, H. M. (2025). Engaging students with soft robotics. *Nature Reviews Bioengineering* 3, 912–913. 10.1038/s44222-025-00372-9

[20] Bacon, A., & Golecki, H. M. (2025). A Design-Based Research Course for Biomedical Engineering Students. Paper presented at 2025 ASEE Annual Conference & Exposition, Montreal, Quebec, Canada. 10.18260/1-2—55361

[21] Floyd, K. S., Harrington, S., & Santiago, J. (2009). The effect of engagement and perceived course value on deep and surface learning strategies. *Informing Science*, 12, 181.

[22] Biggs, J. (2023). Assessing for quality in learning. In Assessment to Promote Deep Learning (pp. 65-68). Routledge.
[23] Biggs, J., & Tang, C. (2015). Constructive Alignment: An Outcomes-Based Approach to Teaching Anatomy. In Teaching Anatomy (pp. 31-38). 10.1007/978-3-319-08930-0_4
[24] Zeegers, P. (2001). Approaches to learning in science: A longitudinal study. *British Journal of Educational Psychology*, 71, 115-132. 10.1348/000709901158424.
[25] Hands, C., & Limniou, M. (2023). A Longitudinal Examination of Student Approaches to Learning and Metacognition. *Journal of Higher Education Theory and Practice*, 23 (19), 125-150. 10.33423/jhetp.v23i19.6677
[26] Cvetkovic, C., Jahnke, K., Miriyala, M., & Owen, B. (2024). Empowering Future Engineers by Integrating Science Communication into Undergraduate Labs. Paper presented at 2024 IEEE Frontiers in Education (FIE) Conference, Washington, DC. 10.1109/FIE61694.2024.10893522
[27] Cvetkovic, C., Jahnke, K., Lindley, S., & Owen, B. (2024). Embedding the Entrepreneurial Mindset into Undergraduate Bioengineering Courses: Two Instructional Laboratory Case Studies. Paper presented at 2025 American Society for Engineering Education (ASEE) Annual Conference & Exposition, Portland, Oregon. 10.18260/1-2--47232
[28] Cvetkovic, C., Lindley, S., Golecki, H. M., & Krencik, R. (2024). Biofabrication of Neural Organoids: An Experiential Learning Approach for Instructional Laboratories. *Biomedical Engineering Education*, 4, 409-419. 10.1007/s43683-024-00145-7
[29] https://engineeringunleashed.com/framework
[30] Hoyle, M. R., Opolz, M. D., Raymond-Bertrand, J., Admal, N. C., Chang, W. L., Golecki, T., Halloran, K. M., Luetkemeyer, C., Mercer, B., West, M., & Kersh, M. (2025). Making space for curiosity, connection, and creating value by integrating real-world examples into engineering education. Paper presented at 2025 ASEE Annual Conference & Exposition, Montreal, Quebec, Canada. 10.18260/1-2--56950
[31] Golecki, H., Chang, W., Johnson, B. et al. (2026). Using Podcasts to Motivate Bioengineering Capstone Students Toward Learning and Career Exploration. *Biomedical Engineering Education*, 6, 171-181.1007/s43683-025-00207-4
[32] Engle, R. A. (2006). Framing Interactions to Foster Generative Learning: A Situative Explanation of Transfer in a Community of Learners Classroom. *The Journal of the Learning Sciences*, 15(4), 451-4YY.
[33] Bethke, E., Ansari, A., Amos, J. R., Bradley, J., Ochia, R., & Golecki, H. M. (2024). Bridging Extracurricular Skill Needs in Bioengineering Capstone Design with Just-in-Time Workshops. Paper presented at 2024 ASEE Annual Conference & Exposition, Portland, Oregon. 10.18260/1-2--48410

Appendices

Appendix A. QR Code for BIOEref website: https://bioe.refpages.org/

Appendix B. Early (n = 49) vs. late (n = 22) semester medians across each study process question (SPQ) scale category (subscales and main scales). Effect sizes were calculated using rank-biserial correlation. In the effect size column, "E > L" indicates values in the early semester group tend to be higher than in the late semester group, and "E < L" indicates that values in the late semester group tend to be higher than in the early semester group. Effect magnitude is denoted as + (small, |r| < 0.3), ++ (medium, 0.3 < |r| < 0.5), and +++ (large, |r| > 0.5).

	SPQ Scale	Early Semester (E) Median	Late Semester (E) Median	Effect Size
Subscale	Deep Motive (DM)	**16**	15.5	0.14 (*E > L* | +)
	Surface Motive (SM)	11	11	-0.09 (*E < L* | +)
	Deep Strategy (DS)	**15**	13.5	0.27 (*E > L* | +)
	Surface Strategy (SS)	14	**15.5**	-0.19 (*E < L* | +)
Main Scale	Deep Approach (D)	**31**	29	0.21 (*E > L* | +)
	Surface Approach (S)	25	**27**	-0.15 (*E < L* | +)

Appendix C. Significant differences in medians (with noted p values) of main scale items: Deep Approach (D) and Surface Approach (S), at early vs. late timepoints. Mann-Whitney U tests were conducted for each scale. Bonferroni corrections were applied separately within main scale groups (with $\alpha = 0.0125$ for 4 comparisons). *** = p < 0.01.

		(p-values, *with comparisons of medians*)			
Main Scales		Early (E)		Late (L)	
		Deep Approach (D)	Surface Approach (S)	Deep Approach (D)	Surface Approach (S)
Early (E)	Deep Approach (D)		< 0.001*** *D > S*	0.15 *E > L*	
	Surface Approach (S)				
Late (L)	Deep Approach (D)				
	Surface Approach (S)		0.30 *L > E*	0.16 *D > S*	

Appendix D. Significant differences (with noted p values) in medians of subscale items: Deep Motive (DM), Surface Motive (SM), Deep Strategy (DS), and Surface Strategy (SS), at early (E) vs. late (L) timepoints. Mann-Whitney U tests were conducted for each subscale. Bonferroni corrections were applied separately within subscale groups (with $\alpha = 0.00625$ for 8 comparisons). *** = $p < 0.01$.

		(p-values, *with comparisons of medians*)							
		Early (E)				**Late (L)**			
Subscales		Deep Motive (DM)	Surface Motive (SM)	Deep Strategy (DS)	Surface Strategy (SS)	Deep Motive (DM)	Surface Motive (SM)	Deep Strategy (DS)	Surface Strategy (SS)
Early (E)	Deep Motive (DM)		0.85 *DM > SM*			0.36 *E > L*			
	Surface Motive (SM)						0.56 *E = L*		
	Deep Strategy (DS)				<0.001*** *DS > SS*			0.07 *E > L*	
	Surface Strategy (SS)								0.20 *L > E*
Late (L)	Deep Motive (DM)						0.17 *DM > SM*		
	Surface Motive (SM)								
	Deep Strategy (DS)								< 0.001*** *SS < DS*
	Surface Strategy (SS)								

Appendix E. Early (n = 49) vs. late semester (n = 22) medians across each study process question (SPQ). Mann-Whitney U tests were conducted independently as single comparisons for each question. Effect sizes were calculated using rank-biserial correlation. In the effect size column, "E > L" indicates values in the early semester group tend to be higher than in the late semester group, and "E < L" indicates that values in the late semester group tend to be higher than those in the early semester group. Effect magnitude is denoted as + (small, $|r| < 0.3$), ++ (medium, $0.3 < |r| < 0.5$), and +++ (large, $|r| > 0.5$). ** = $p < 0.01$.

	Question	**Early Median**	**Late Median**	**Effect Size**	**p**
Deep Motive (DM)	Q1: I find that at times studying gives me a feeling of deep personal satisfaction.	4	**4**	-0.12 (E < L | +)	0.40
	Q5: I feel that virtually any topic can be highly interesting once I get into it.	**4**	3	0.28 (E > L | +)	0.06
	Q9: I find that studying academic topics can at times be as exciting as a good novel or movie.	**3**	3	0.12 (E > L | +)	0.41
	Q13: I work hard at my studies because I find the material interesting.	**4**	4	0.04 (E > L | +)	0.79
	Q17: I come to most classes with questions in mind that I want answering.	**2**	2	0.18 (E > L | +)	0.19
Deep Strategy (DS)	Q2: I find that I have to do enough work on a topic so that I can form my own conclusions before I am satisfied.	**4**	4	0.17 (E > L | +)	0.24

	Q6: I find most new topics interesting and often spend extra time trying to obtain more information about them.	**3**	2	0.22 (E > L | +)	0.12
	Q10: I test myself on important topics until I understand them completely.	**4**	4	0.11 (E > L | +)	0.42
	Q14: I spend a lot of my free time finding out more about interesting topics which have been discussed in different classes.	**2**	1.5	0.39 (E > L | ++)	0.005 **
	Q18: I make a point of looking at most of the suggested readings that go with the lectures.	**3**	2.5	0.12 (E > L | +)	0.41
Surface Motive (SM)	Q3: My aim is to pass the course while doing as little work as possible.	**2**	2	0.09 (E > L | +)	0.54
	Q7: I do not find my course very interesting so I keep my work to the minimum.	**2**	2	0.17 (E > L | +)	0.23
	Q11: I find I can get by in most assessments by memorizing key sections rather than trying to understand them.	2	**2**	-0.18 (E < L | +)	0.19
	Q15: I find it is not helpful to study topics in depth. It confuses and wastes time, when all you need is a passing acquaintance with topics.	2	**2**	-0.24 (E < L | +)	0.08
	Q19: I see no point in learning material which is not likely to be in the examination.	3	**2.5**	<-0.01 (E < L | +)	0.99
Surface Strategy (SS)	Q4: I only study seriously what's given out in class or in the course outlines.	4	**4**	-0.15 (E < L | +)	0.29
	Q8: I learn some things by rote, going over and over them until I know them by heart even if I do not understand them.	**3**	2	0.11 (E > L | +)	0.45
	Q12: I generally restrict my study to what is specifically set as I think it is unnecessary to do anything extra.	2	**3**	-0.17 (E < L | +)	0.24
	Q16: I believe that lecturers shouldn't expect students to spend significant amounts of time studying material everyone knows won't be examined.	3	**3.5**	-0.16 (E < L | +)	0.28
	Q20: I find the best way to pass examinations is to try to remember answers to likely questions.	2	**3**	-0.22 (E < L | +)	0.13

Appendix F. Non-User (n = 10) vs. User (n = 12) medians across each study process question (SPQ) scale category (subscales and main scales). Effect sizes were calculated using rank-biserial correlation. In the effect size column, "U > N" indicates values in the user group tend to be higher than in the non-user group, and "U < N" indicates that values in the user group tend to be lower than in the non-user group. Effect magnitude is denoted as + (small, |r| < 0.3), ++ (medium, 0.3 < |r| <0.5), and +++ (large, |r| > 0.5).

	SPQ Scale	**Non-Users (N) Median**	**Users (U) Median**	**Effect Size**
Subscale	Deep Motive (DM)	15	**15.5**	0.25 ($U > N$ | +)
	Surface Motive (SM)	**12**	11	-0.23 ($U < N$ | +)
	Deep Strategy (DS)	13	**14**	0.20 ($U > N$ | +)
	Surface Strategy (SS)	**16**	14	-0.39 ($U < N$ | ++)
Main Scale	Deep Approach (D)	29	**30**	0.21 ($E > L$ | +)
	Surface Approach (S)	**28**	24	-0.15 ($E < L$ | +)

Appendix G. Significant changes in medians (with noted p values) of main scale items: Deep Approach (D) and Surface Approach (S), for Users (U) vs. Non-Users (N). Mann-Whitney U tests were conducted for each group. Bonferroni corrections were applied separately within main scale groups (with $\alpha = 0.0125$ for 4 comparisons).

		(p-values, *with comparisons of medians*)	
Main Scales		**Non-Users (N)**	
		Deep Approach (D)	Surface Approach (S)
Users (U)	Deep Approach (D)	0.25 $U > N$	
	Surface Approach (S)		0.14 $N > U$

Appendix H. Significant differences (with noted p values) in medians of subscale items: Deep Motive (DM), Surface Motive (SM), Deep Strategy (DS), and Surface Strategy (SS), for Users (U) vs. Non-Users (N). Mann-Whitney U tests were conducted for each subscale. Bonferroni corrections were applied separately within subscale groups (with $\alpha = 0.00625$ for 8 comparisons).

		(p-values, *with comparisons of medians*)			
Subscales		**Users (U)**			
		Deep Motive (DM)	Surface Motive (SM)	Deep Strategy (DS)	Surface Strategy (SS)
Non-Users (N)	Deep Motive (DM)	0.35 $U > N$			
	Surface Motive (SM)		0.38 $N > U$		
	Deep Strategy (DS)			0.46 $U > N$	
	Surface Strategy (SS)				0.12 $N > U$

Appendix I. Non-User (n = 10) vs. User (n = 12) medians across each study process question (SPQ). Mann-Whitney U tests were conducted independently as single comparisons for each question. Effect sizes were calculated using rank-biserial correlation. In the effect size column, "U > N" indicates values in the user group tend to be higher than in the non-user group, and "U < N" indicates that values in the user group tend to be lower. Effect magnitude is denoted as + (small, $|r| < 0.3$), ++ (medium, $0.3 < |r| < 0.5$), and +++ (large, $|r| > 0.5$).

<table>
<tr><th></th><th>Question</th><th>Non-Users Median</th><th>Users Median</th><th>Effect Size</th><th>p</th></tr>
<tr><td rowspan="5">Deep Motive (DM)</td><td>Q1: I find that at times studying gives me a feeling of deep personal satisfaction.</td><td>3</td><td>4</td><td>0.19 (U > N | +)</td><td>0.46</td></tr>
<tr><td>Q5: I feel that virtually any topic can be highly interesting once I get into it.</td><td>3</td><td>3</td><td>-0.04 (U < N | +)</td><td>0.87</td></tr>
<tr><td>Q9: I find that studying academic topics can at times be as exciting as a good novel or movie.</td><td>2</td><td>3</td><td>0.48 (U > N | ++)</td><td>0.059</td></tr>
<tr><td>Q13: I work hard at my studies because I find the material interesting.</td><td>3</td><td>4</td><td>0.34 (U > N | ++)</td><td>0.18</td></tr>
<tr><td>Q17: I come to most classes with questions in mind that I want answering.</td><td>2</td><td>2</td><td>-0.22 (U < N | ++)</td><td>0.42</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td rowspan="5">Deep Strategy (DS)</td><td>Q2: I find that I have to do enough work on a topic so that I can form my own conclusions before I am satisfied.</td><td>3.5</td><td>4</td><td>0.12 (U > N | +)</td><td>0.67</td></tr>
<tr><td>Q6: I find most new topics interesting and often spend extra time trying to obtain more information about them.</td><td>2</td><td>2</td><td>0.15 (U > N | +)</td><td>0.58</td></tr>
<tr><td>Q10: I test myself on important topics until I understand them completely.</td><td>4</td><td>4</td><td>0</td><td>1.00</td></tr>
<tr><td>Q14: I spend a lot of my free time finding out more about interesting topics which have been discussed in different classes.</td><td>1.5</td><td>1.5</td><td>0</td><td>1.00</td></tr>
<tr><td>Q18: I make a point of looking at most of the suggested readings that go with the lectures.</td><td>3</td><td>2</td><td>-0.01 (U < N | +)</td><td>1.00</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td rowspan="4">Surface Motive (SM)</td><td>Q3: My aim is to pass the course while doing as little work as possible.</td><td>2</td><td>2</td><td>0.06 (U > N | +)</td><td>0.82</td></tr>
<tr><td>Q7: I do not find my course very interesting so I keep my work to the minimum.</td><td>2</td><td>1.5</td><td>-0.13 (U < N | +)</td><td>0.63</td></tr>
<tr><td>Q11: I find I can get by in most assessments by memorizing key sections rather than trying to understand them.</td><td>2</td><td>2.5</td><td>-0.15 (U < N | +)</td><td>0.58</td></tr>
<tr><td>Q15: I find it is not helpful to study topics in depth. It confuses and wastes time, when all you need is a passing acquaintance with topics.</td><td>2</td><td>2</td><td>-0.20 (U < N | +)</td><td>0.46</td></tr>
</table>

	Q19: I see no point in learning material which is not likely to be in the examination.	**3**	2	-0.06 (U < N | +)	0.82
Surface Strategy (SS)	Q4: I only study seriously what's given out in class or in the course outlines.	**4**	3.5	-0.33 (U < N | ++)	0.20
	Q8: I learn some things by rote, going over and over them until I know them by heart even if I do not understand them.	**2.5**	2	-0.38 (U < N | ++)	0.14
	Q12: I generally restrict my study to what is specifically set as I think it is unnecessary to do anything extra.	3	**3**	0.10 (U > N | +)	0.72
	Q16: I believe that lecturers shouldn't expect students to spend significant amounts of time studying material everyone knows won't be examined.	**3.5**	3.5	-0.08 (U < N | +)	0.77
	Q20: I find the best way to pass examinations is to try to remember answers to likely questions.	**3**	2	-0.34 (U < N | ++)	0.18

Appendix J. Changes in medians across each study process scale category), organized by student self-reported usage trends over the course of the semester. Bolded values indicate the larger between deep vs. surface scores for the main scale or sub-scales. Due to small sample sizes, IQR was not calculated.

Usage Group	**Deep Motive (DM)**	**Surface Motive (SM)**	**Deep Strategy (DS)**	**Surface Strategy (SS)**	**Deep Approach (D)**	**Surface Approach (S)**
Increased Use (n = 5)	**17.0**	11.0	**14.0**	11.0	**31.0**	22.0
Consistent Use (n = 5)	**16.0**	11.0	15.0	15.0	**33.0**	26.0
Reduced Use (n = 2)	**14.5**	11.5	13.5	**18.0**	28.0	**29.5**
No Usage (n = 10)	**15.0**	12.0	13.0	**16.0**	**29.0**	28.0