Using inquiry-based learning to teach principles of regenerative mechanobiology

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INTRODUCTION: Mechanobiology is an interdisciplinary field that aims to understand how physical forces impact biological systems. Understanding the mechanisms by which a cell's physical environment can impact its phenotype is important because many orthopaedic pathologies are associated with altered tissue stiffness.[1] Furthermore, delivering appropriate mechanical cues has led to mechanobiology-inspired therapeutics for numerous musculoskeletal tissues, including bone,[2] tendon,[3] and muscle.[4] To continue developing such novel therapies, there is a need to educate diverse students about mechanobiology. Hands-on educational modules that employ inquiry-based learning (IBL) are an effective way of teaching bioengineering and mechanobiology.[5] However, there is a dearth of published IBL mechanobiology modules that can be broadly deployed at institutions with limited resources (*e.g.,* primarily undergraduate institutions (PUIs) and community colleges). To address this issue, we designed, implemented, and evaluated an accessible mechanobiology module, which used inexpensive materials to teach undergraduate students about cell-biomaterial interactions.

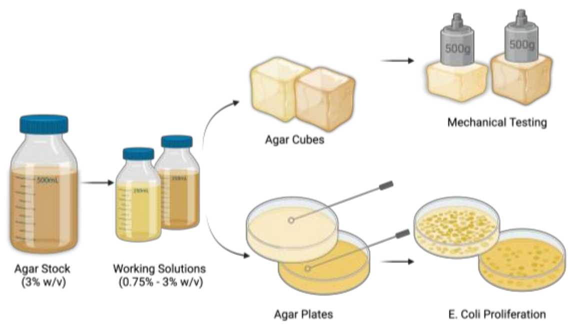

Figure 1. Schematic of inquiry-based learning (IBL) mechanobiology module.

METHODS: The IBL mechanobiology module was hosted over two consecutive days, with a 3-hr session each day. We deployed the module at the Community College of Philadelphia, the University of Puerto Rico (UPR) – Cayey, and the UPR – Mayaguez. The module can be divided into 3 stages: (1) pre-activity exercises, (2) IBL activity, and (3) post-activity exercises. During the pre-activity exercise, instructors used active learning to provide a brief background on mechanobiology, then guided students through student-led discussion about independent variables, mechanical testing methods, and testable hypotheses. After the pre-activity exercises, students cast agar hydrogel cubes and agar plates with different macromer concentrations of agar, mechanically tested hydrogel cubes, and cultured *E. coli* on agar plates. During the second day of the IBL activity, students analyzed their mechanical data and qualitatively assessed how substrate stiffness impacts *E. coli* proliferation (**Fig 1**). After completing the IBL activity, students participated in a student-led post-activity exercise to discuss their findings, limitations of the experiment, and real-world applications of mechanobiology. The module was evaluated using pre/post-tests to assess learning gains and validated pre/post-surveys[6] to assess improvements in scientific confidence. Average pre/post-test and pre/post-survey results were compared using paired Student's t-tests ($\alpha = 0.05$).

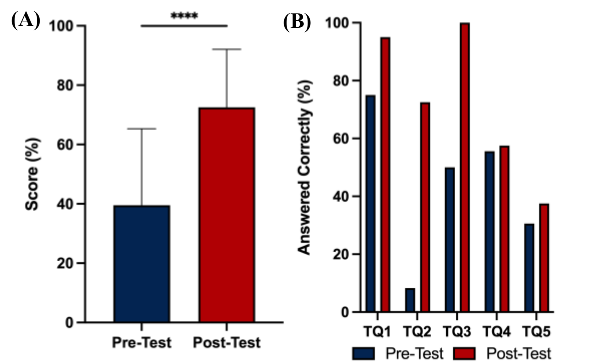

Figure 3. Students showed significant learning gains by pre/post-test. (A) *Average student pre/post-test scores.* ***(B)*** *Percentage of students who answered individual questions correctly on pre/post-tests. **** = p<0.0001.*

RESULTS: 73 undergraduate students registered for our IBL mechanobiology module, and a vast majority of our cohort consisted of individuals who are underrepresented in STEM based on race/ethnicity (>80%) or gender (>50%). Among the students who registered for our module, forty students (N=40) provided informed consent to participate in our study. Results from our pre/post-test showed that students experienced significant learning gains from participating in our module. Specifically, the average score increased from 39.5% on the pre-test to 72.5% on the post-test (**Fig 2A**). In addition to increases in overall score, we found that the percentage of students who answered each test question (TQ) correctly was greater in the post-test than the pre-test (**Fig 2B**). Students also experienced significant improvements in all measured categories of scientific confidence, as assessed using the Scientific Literacy and Student Value in Inquiry-guided Lab Survey (SLIGS) (**Fig 3**).[6] Overall, our results demonstrate that completing this IBL mechanobiology module effectively taught students principles of mechanobiology and enhanced their confidence with performing scientific inquiry.

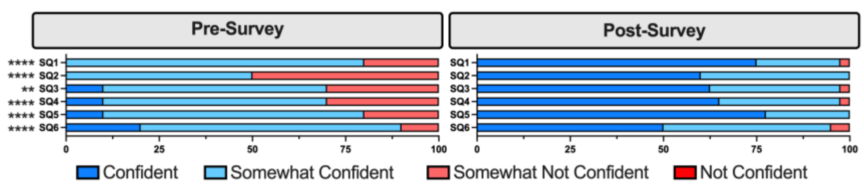

Figure 2. Students showed significant improvements in scientific confidence by pre/post-survey. *** = p,0.01, **** = p<0.0001.*

DISCUSSION: Mechanobiology is important for understanding many orthopaedic diseases and developing novel therapies. To continue harnessing principles of mechanobiology for improving human health, there is a societal need to teach diverse students principles of mechanobiology. Unfortunately, there is a dearth of published mechanobiology modules that are accessible to PUIs, community colleges, and other institutions with limited resources. This poses a major challenge because the underrepresented minority (URM) students that frequently attend these institutions will have limited access to the formative modules that have been shown to increase participation in STEM.[7] To address this challenge, we designed, implemented, and evaluated an accessible mechanobiology module. To make our IBL mechanobiology module more accessible, we used inexpensive materials (*i.e.*, agar and *E. coli*) and eliminated the need for expensive equipment (*i.e.,* mechanical testing devices and biosafety cabinets). Though inexpensive, the module effectively taught principles of mechanobiology and promoted similar learning gains to other published bioengineering modules.[8] Moreover, the IBL pedagogy employed in this module enhanced students' confidence with scientific inquiry. Such innovative and inexpensive outreach modules, which can be easily deployed to URM students, are important for increasing the diversity of trainees in orthopaedics. We recognize that this single module cannot be a panacea for resolving systemic issues around diversity, equity, and inclusion (DEI) in orthopaedics; however, this module is one example of an effective way to empower URM students to advance in the field.

SIGNIFICANCE: Developing accessible outreach modules is important for increasing the representation of URM students in orthopaedics. The IBL mechanobiology module presented uses inexpensive materials to effectively teach students mechanobiology and raise their scientific confidence.

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