BENG 110 MUSCULOSKELETAL BIOMECHANICS
Fall Quarter 2023

Statics, Dynamics and Solid Mechanics of the Musculoskeletal System
September 28th - December 15th, 2023
Tuesdays and Thursdays 11:00 am - 12:20 pm, Podemos room 1A18 (8th College)
Schedule of Lectures
Unless otherwise notified all lectures will be in person

To use Kahoot! in class, download the mobile app for iOS, Android, or Huawei, or go to https://kahoot.it/

Join PlayPosit with your UCSD email account to view annotated videos
https://www.playposit.com/join-class/227970-1297230

Class Code: 227970-1297230

Instructor
Dr. Andrew McCulloch, Distinguished Professor of Bioengineering and Medicine
Shu Chien Chancellor's Endowed Chair in Engineering and Medicine

Graduate Student Instructors
Shayan Raofi, Bioengineering graduate student, email sraofi@ucsd.edu
Simar Sharma, Bioengineering graduate student, email sis003@ucsd.edu

Questions
Before posting questions about course logistics please read all course syllabus and scheduling material carefully. For timely response to all course questions, please use the course discussion board on Canvas. For personal questions, please email TAs first. As needed, TAs will refer questions that they cannot answer to the instructor. Please be aware of the possibility of miscommunication in written correspondence and compose your messages in a professional, respectful, and constructive manner.

Lecture Hours
Tuesday and Thursday 11:00 am-12:20 pm Podemos 1A18

Join PlayPosit with your UCSD email account to view annotated online lectures:
https://www.playposit.com/join-class/227970-1297230

Kahoot! To use Kahoot! in class, download the mobile app for iOS, Android, or Huawei, or go to https://kahoot.it/

TA-Led Problem Solving Sessions
Sessions will be in-person starting September 29th

TA: Shayan Raofi, Wednesday 9:00-9:50 am York 3000A
TA: Simar Sharma, Friday 4:00 - 4:50 pm CSB 002
Backup session, Friday 12:00-12:50 pm CENTR 218 (NO TA YET, DO NOT ATTEND UNLESS ANNOUNCED)

Instructor Office Hours
Tuesdays 5:00 pm via zoom, https://ucsd.zoom.us/j/98398779780
Please log on before 5:15 to ensure you will find me. I will stay as long as necessary whenever possible but if there is no one waiting at 5:15, I generally assume no one else is coming and end the zoom session.

TA Office Hours
Shayan Raofi, Monday, 2:00-3:00 pm, Zoom, Meeting ID:
https://ucsd.zoom.us/j/95987108458?pwd=Rm1DekVkK0JseVZzdi9PT2svM2QzZz09
Simar Sharma, Thursday, 6:00-7:00 pm, Zoom, Meeting ID: https://ucsd.zoom.us/j/97511267364

Prerequisites
MATH 20D, MATH 20E or MATH 31CH; MATH 18 or MATH 31AH; PHYS 2C

Learning Objectives
Statics, dynamics and solid mechanics of hard and soft musculoskeletal tissues. The concepts, notations, theories and applications of statics, dynamics and solid mechanics to engineering problems in general and to musculoskeletal biomechanics problems in particular will be covered. Topics include the forces, moments, static equilibrium, kinematics, kinetics applied to human mechanics and movement as well as stress, strain and material properties of musculoskeletal tissues. Theoretical problem-solving and the role of engineering design will be emphasized with weekly homework assignments posted at this website. BENG 110 is a required prerequisite for BENG 112A and BENG 112B Biomechanics.

Course Material
Lectures, homework, problem solving sessions, and reading assignments are your most valuable resources in this course. While attendance is not required, it is strongly encouraged that you attend all class meetings and your assigned discussion section in real time, read all assigned readings and view all recommended online videos. We make every effort to give you access to a wide range of course materials by recommending *textbook reading*, providing copies of *lecture notes*, additional *handouts*, *worked examples*, *self quizzes*, *practice problems* and *annotated videos*. Because this course is an introduction to three big topics in mechanics—statics, dynamics and solid mechanics— these books and materials *inevitably go significantly beyond the scope that can be covered in one quarter*.

We encourage you to take advantage of these reference materials, but please be reassured that you will *only be examined on materials that we cover in lectures, discussion sections and homework assignments*. We wish there was a single textbook that only covered the scope of this course but unfortunately there isn't one. The *only way to know* whether you should study a particular topic for midterms and finals is to attend online lectures and discussion sections and complete the homeworks and practice problems. Please check the Canvas course website frequently for new material. Not all new material added to the website will be announced.

Schedule of Lectures

Website and Online Resources
Canvas.ucsd.edu will be used to distribute all course materials and information, including schedule/syllabus, handouts, supplementary material, homework assignments, exams, and grades, as well as for discussion boards, etc. Students should have an ACS username and password for access; if not, please email a TAs to make arrangements to get one. We will use Gradescope for homework submission and grade distribution and Canvas for online discussions. All course materials will all be distributed *via* the course site on Canvas, which you can access with your ucsd.edu account. All announcements and assignments will be made via Canvas and Gradescope. During class, we will use Kahoot! for quizzes. Wrong Kahoot! answers will never affect your grade but they will be used to confirm your live participation in class.

Course Format and Expectations
Students are expected to review lecture notes, do any assigned reading and prepare questions in advance of each lecture. Lectures may not always repeat all of these materials verbatim but rather focus on applying concepts to problem solving and on answering student questions. Live lectures will be recorded, but since they will be intentionally interactive, the greatest benefit will come from attending them live. PlayPosit videos have been designed to be used asynchronously as adjuncts to the live lectures but they do not cover exactly the same material. They are a resources to help you that many students report finding helpful. They include quiz

questions. Your answers to the quiz questions will not affect your grade, but they do help us to identify topics to focus on in Discussion sections. Note that the quizzes are not primarily intended to test your understanding of the online lecture material. Rather, they are intended to make you think about and apply lecture concepts or to demonstrate how they can be taken further. They are intended to promote self-learning.

20% of the grade will be awarded for regular participation. For flexibility, participation is based on a point system. Points can be scored for attendance in person at lectures and discussion sections, submitting homework problems on time, submitting solutions to ungraded practice problems with homeworks. The full participation score will be awarded for the point equivalent of attendance at every lecture and one discussion section per week, and submitting all homework assignments complete and on time. We may use various cloud-based tools such as Kahoot! to measure attendance and participation. Participation point breakdown:

- Attendance at lectures: 3 points per lecture
- Attendance at discussion sections: 2 points per section
- Each *completed* homework problem submitted via Gradescope on time: 10 points per complete homework (pro-rated for partially complete submissions)
- Each *completed* ungraded practice problem set submitted via Gradescope with on-time homework : 6 points per complete problem set (pro-rated for partially complete submissions)
- Asking or answering well posed subject-matter questions on the class Discussion board: 1 point
- TAs and the instructor will also assign additional participation points for helpful or notable contributions in class and sections, such as asking and answering questions in person.

Exams, midterms and homeworks will cover *all* of the material covered in the assigned reading, homeworks, distributed notes and quizzes, not just those topics covered during the lecture sessions. To ensure that there is time to answer questions during lectures, all course material can not always be covered during lectures. However, when there is significant material not covered in lectures that you need to be familiar with, you will be told about it in class.

For an interesting insight into how we learn most effectively, one of my students sent me this YouTube video that I highly recommend: https://www.youtube.com/watch?v=UBVV8pch1dM

The Big BENG
Have you heard of the The Big BENG? It is a YouTube project created by UC San Diego Bioengineering students to help you learn key concepts in major Bioengineering courses. Because this project started last year in BENG 110, they have the most complete content for this course. Check it out and subscribe on YouTube at https://www.youtube.com/channel/UCRZyaTbjfAh7weyGy0MRnZw.

Textbooks
There is no *required* textbook for this course. However, while lecture notes covering the full scope of the course content are provided, background reading is helpful and many students find it essential. Humphrey and O'Rourke is required for BENG 112A and BENG 112B and has some useful background material for this course. Note that the first Edition of Humphrey and O'Rourke is by Humphrey and Delange. There are many statics and dynamics and engineering mechanics textbooks as well as a few biomechanics books that cover some of the material in this course. The main differences are in notations and problem sets. Beer and Johnston is on *Statics and Dynamics* and has lots of worked examples. Used copies of these books are often available and earlier editions are satisfactory. Especially if you are not planning to take BENG 112A and 112B, the new book by Uchida and Delp is recommended.

1. FP Beer and ER Johnston. *Vector Mechanics for Engineers: Statics and Dynamics*, 12th Edition, McGraw Hill, 2018. ISBN: 978-1259638091. This book can also be rented from Amazon for $37.
2. N Özkaya, D Leger, D Goldsheyder, M Nordin. *Fundamentals of Biomechanics: Equilibrium, Motion, and Deformation* 4th ed., 2017. ISBN: 978-3319447377
3. SJ Hall. *Basic Biomechanics*, 8th Edition. McGraw-Hill, 2018. ISBN-13: 978-1259913877

4. JD Humphrey and SL O'Rourke, *An Introduction to Biomechanics: Solids and Fluids, Analysis and Design*, Springer-Verlag, 2015. ISBN: 978-1493926220
5. Thomas K. Uchida, Scott L Delp. *Biomechanics of Movement: The Science of Sports, Robotics, and Rehabilitation.* MIT Press 2021, 1st Edition. ISBN: 978-0262044202

I have requested that all of these books be placed on course reserve by the library. You may be able to rent or buy the eBook version of the textbook at a considerable discount compared with the hard copy textbook. UC San Diego Bookstore through Canvas may be able to offer books to buy or rent free for the first two weeks of classes. For any questions about billing please contact textbooks@ucsd.edu.

See the RedShelf link here for more information: https://ucsandiegobookstore.redshelf.com

Grading

Homework Assignments	20%
Participation	20%
Midterm Exam (Open notes)	15%
Final Project	20%
Final Examination (Closed book and notes)	25%

Letter Grading Scale Guidance

Letter Grade	Total Score
A+	97-100
A	93-97
A-	90-93
B+	87-90
B	83-87
B-	80-83
C+	77-80
C	73-77
C-	70-73
D	67-70
D	63-67
D	60-73
F	<60.0

Homework, Exam and Grading Policies
Homeworks can *only be submitted online as a PDF file scanned or photographed from the original.* All assignments will be posted on ***Canvas*** but will be assigned, submitted, graded, returned (and if necessary regraded) *exclusively* via ***Gradescope***, which allows us to provide fast and accurate feedback on your work. Gradescope has been enabled in Canvas. Your Gradescope login is your university email. See this document for more information on proper use of Gradescope.

To submit your assignments on Gradescope, you will need to upload a high quality scan or photo to your Gradescope account. If using a smart phone to photograph submitted materials, use an App such as TinyScanner, which enables you to enhance contrast and correct shape distortions easily. Graded exams and final and midterm exam grades will also be distributed via Gradescope. As soon as grades are posted, you will be notified immediately so that you can log in and see your feedback. You may also submit regrade requests if you feel we have made a mistake.

Grading Policy. While it is acceptable to study together, homework turned in must be your own work and must be *hand written except when otherwise specified*. Homeworks received after worked solutions have been handed out will receive no credit. Regrades: In fairness to all students, work is only regraded when there is evidence of grading error. We reserve the right to regrade an entire piece of work. Regrade requests should be submitted via Gradescope.

Late Homework Policy. Although we attempt to accept late homework, assignments submitted more than 24 hours late but not more than 48 hours late may receive a 10% penalty. Assignments submitted more than 48 hours late and less than 72 hours late may receive a 20% penalty. Assignments submitted more than 72 hours late may receive a 30% penalty. Homeworks will not be accepted after solutions or design grading summaries are posted. A doctor's note or other written explanation will be required for exceptions to this policy.

Midterm Exam. The midterm will be open (printed paper) notes and held during scheduled extra lecture hour. Exams can only be taken remotely with prior permission for reasons allowed under university Covid policy such as illness or travel restrictions.

Final Exams. The final exam will be closed book and notes and held in person at the time and place specified in the Schedule of Classes. Exams can only be taken remotely with prior permission for reasons allowed under university Covid policy such as illness or travel restrictions. Note that we will never assign more than one test per day, all exam and midterm instructions will be written, and we are unable to answer any questions *about the test during the test*, even if it turns out that that test contains a mistake or ambiguity. This is because we do not have enough instructors and TAs to simultaneously proctor all students taking a test at the same time.

Makeup and Accommodations. If a student is unable to take an exam for valid reasons, the student must notify the instructor immediately and all attempts will be made to offer an alternative time and equivalent exam. Allow on week to schedule a makeup test. Valid reasons include illness and family emergencies. Documented proof of the reason for absence may be required per university policy. For more information, see https://senate.ucsd.edu/operating-procedures/educational-policies/courses/epc-policies-on-courses/policy-exams-including-midterms-final-exams-and-religious-accommodations-for-exams/

For make-up tests and students requiring accommodations for tests we will be using the Triton Testing Center. You need to register for this service and make an appointment for the makeup test or accommodations three days in advance. Accommodation tests will be conducted at the same time as scheduled in class tests unless the time or day of the test is itself the reason for the accommodation.

Computing

Computer and network access may be needed for assignments in this course. All UCSD engineering students are eligible for computer accounts through Academic Computing Services. You can see what kind of account you have on-line using the Account Lookup Tool at https://sdacs.ucsd.edu/~icc/index.php. Computing labs are available throughout the campus including room 161 in Powell-Focht Bioengineering Hall.

For assistance with UCSD instructional computing facilities, do not come to the instructor or TAs as they are not managed by departmental personnel. You can email questions to acs-consult@ucsd.edu . Student consultants are available to help in ACS labs on weekdays and evenings. Students are expected to be familiar with MATLAB for engineering computing including linear algebra and differential equations. Proficient students may be permitted to submit computer solutions in Python using a JuPyter Notebook in lieu of MATLAB.

For assistance with UCSD instructional computing facilities, do not come to the instructor or TAs as they are not managed by departmental personnel. You can email questions to acs-consult@ucsd.edu.

Integrity of Scholarship
The Department of Bioengineering adheres to the UCSD Policy on Integrity of Scholarship. This Policy states that "Students are expected to complete the course in compliance with the instructor's standards. No student shall engage in any activity that involves attempting to receive a grade by means other than honest effort ..." The full descriptions of these polices, as well as others regarding acceptable behavior are given in the Student Code of Conduct at http://students.ucsd.edu/student-life/_organizations/student-conduct/regulations/22.00.html. The regulations on exams, grading and integrity of scholarship are also in the General Catalog at http://www.ucsd.edu/catalog/front/AcadRegu.html. Helpful resources on understanding and complying with these regulations can be found at the Academic Integrity Office website.

Students are not discouraged from discussing homework assignments among themselves or engaging in group study. However, **individual homework assignments must be the sole work of the submitting student**. Specific guidance will be given in the case of group projects. When submitted coursework incorporates material authored by a third party, the source should always be attributed according to the accepted standards of scholarly endeavor. Material taken from the internet or other forms of electronic media are subject to the same requirements of attribution applicable to printed reference sources or materials. Work suspected of being tainted by plagiarism will receive no credit. **All cases of suspected academic dishonesty** including *collaboration*, *plagiarism* and *cheating* as defined by UCSD regulations **will be referred to the UCSD Academic Integrity Coordinator.**

In cases of suspected academic dishonesty including cheating in an examination or altering graded work and resubmitting it, the student will be handed a copy of the student conduct code, and the case will be referred to the appropriate dean. The academic penalty for a finding of serious academic dishonesty will generally be a grade of F. If a case of academic dishonesty is under review by the Academic Integrity Office at the time that grades are due, the student will receive a grade of X pending a final disposition of the case.

Attendance Policy
Lecture and discussion section attendance is not required and you do not needs to request to be excised, but is highly encouraged and is the easiest way to earn participation points.

Copyright
All lectures and course materials, including PowerPoint presentations, tests, outlines, and similar materials, are protected by U.S. copyright law and by University policy. The instructor is the exclusive owner of the copyright for those materials they create. You may take notes and make copies of course materials for your own use. You may also share those materials with another student who is enrolled in or auditing this course. You may not reproduce, distribute or display (post/upload) lecture notes or recordings or course materials in any other way — whether or not a fee is charged — without the instructor's express prior written consent. You also may not allow others to do so. If you do so, you may be subject to student conduct proceedings under the UC San Diego Code of Conduct.

Chat-GPT
You are welcome to use Chat-GPT the way you would use any other online resource for your homeworks and study though no electronic assistance is permitted during exams. As with other sources, you must acknowledge your use of Chat-GPT in any work you submit, and the acknowledgment must include the exact prompt or prompts that you used, the version of Chat-GPT and the date of the prompt. You should also realize that, like many (in fact most) internet sources, Chat-GPT alone will not and should be considered a scientifically reliable, verified or even verifiable source of information. Indeed, you may be asked to critique a Chat-GPT response by identifying errors or misinterpretations it makes. The foregoing also applies to code and you are encouraged to use Chat-GPT to aid you in writing code or using computational tools, but you will need to test the code independently.

Campus Safety Requirements and Expectations
Keeping our campus healthy takes all of us. We are expected to follow the campus safety requirements and pursue personal protection practices to protect yourself and the others around you.

Student Code of Conduct
Please be mindful that TAs are students too and have their own obligations. Let us all pledge to remain respectful, supportive, and adaptable to ensure that everyone's educational goals are met. All participants in the course are bound by the UCSD Code of Conduct, found at: https://students.ucsd.edu/sponsor/student-conduct/policiesandprocedures.html

Expectations

What I expect of you	***What you can expect of me***
Be informed. Read this syllabus carefully and completely so you understand the course structure and expectations.	*Enthusiasm*. To be prepared for each class and to bring my enthusiasm for teaching to each lecture, lab, and office hour meeting.
Be attuned. Keep up with readings and class assignments, as each one builds on the previous one. Be attentive and participate in class.	*Responsiveness*. To respond to emails within 32 hours. For those that know me already, you know that I usually respond faster than this. Emails received on weekends may take longer.
Ethical. A good attitude and maintenance of honest and ethical principles towards me, your classmates, and the execution of the course. Please read UC San Diego's Principles of Community and Conduct Code.	*Timely feedback*. To make every effort to return graded assignments within one week of the submission date and to post solutions as soon as is reasonably possible after the submission date.
Integrity. An honest, fair, responsible, respectful, trustworthy, and courageous effort on all academic work and collaboration. Please read UC San Diego's Policy on Integrity of Scholarship. Then, take the integrity pledge!	*Integrity.* To uphold integrity standards and create an atmosphere that fosters active learning, creativity, critical thinking, and honest collaboration.
Be flexible. Sometimes my schedule gets affected by unavoidable work commitments, necessitating some office hour rescheduling at the last minute.	Reasonable accommodation and understanding for student situations that arise; however, I will not make exceptions for one person that are not available to every other person in the course.

BENG 110 Musculoskeletal Biomechanics

Schedule of Lecture Topics

Reading key:
B&J # = section # in FP Beer and ER Johnston. Vector Mechanics for Engineers: Statics and Dynamics, 10th Edition, McGraw Hill, 2001
JDH# = section # in JD Humphrey and SL Delange, An Introduction to Biomechanics: Solids and Fluids, Analysis and Design, Springer-Verlag, 2004
UD# = section # in TK Uchida, SL Delp. *Biomechanics of Movement: The Science of Sports, Robotics, and Rehabilitation.* MIT Press 2021, 1st edition
OLDN# = section # in N Özkaya, D Leger, D Goldsheyder, M Nordin. *Fundamentals of Biomechanics: Equilibrium, Motion, and Deformation* 4th ed., 2017.
SJH# = section # in SJ Hall. *Basic Biomechanics*, 8th Edition. McGraw-Hill, 2018.

DATE	LECTURE	TOPIC	READING
Sep 28th	1	Introduction to BENG 110 Musculoskeletal Biomechanics	OLDN 1.1-1.3 SJH Ch. 1
Oct 3rd	2	Forces and moments acting on bodies	JDH 1.A1 B&J 1.1-4.1 OLDN Ch.s 2-4 SJH Ch. 3
Oct 5th	3	Static equilibrium of skeletal joints	JDH 1.A1 B&J 4.2-4.9 OLDN Ch.s 5-6 SJH Ch. 13
Oct 10th	4	Biomechanics of movement and walking	UD Ch.s 1-2
Oct 12th	5	Biomechanics of running	UD Ch. 3
Oct 17th	6	Measuring human movement (Dr. Razu)	UD Ch. 7 SJH Ch. 11
Oct 19th	7	Skeletal muscle structure and function	UD Ch. 4
Fri Oct 20th	**4:00-4:50**	**Alex G. Spanos Athletic Performance Center: Assessing human kinematics and kinetics**	
Oct 24th	8	Skeletal muscle mechanics and modeling	UD Ch. 5, SJH Ch. 6
Oct 26th	9	Modeling muscle-driven movement (Dr. Razu)	UD Ch. 8
Oct 31st	10	Structure and mechanical testing of bone: stress and strain in 1D	JDH 2.6-2.7
Friday Nov 3rd	**4:00-4:50**	**MIDTERM EXAM (Open Notes) CSB 002**	
Nov 2nd	11	Bone remodeling	JDH 4.2-4.7 SJH Ch. 4
Nov 7th	12	Stress in 3D	OLDN 14.1-4 JDH 2.2

Nov 9th	13	Cauchy's formula and transformation of stress components	OLDN 16.1-3 JDH 2.2-3
Nov 14th	14	Equilibrium of stresses	JDH 3.1
Nov 16th	15	Strain	JDH 2.5
Nov 21st	16	Strain measurement	
Nov 23rd		**THANKSGIVING HOLIDAY**	
Nov 28th	17	Hooke's law for linearly elastic solids	OLDN 14.6-14.14 JDH 2.6
Nov 30th	18	Bone elasticity	JDH 2.7
Dec 5th	19	Viscoelasticity of soft tissues	JDH 2.6, 11.4 OLDN Ch. 17
Dec 7th	20	Review	
Friday Dec 13th	**FINAL EXAM 11:30am-2:30pm closed book/notes (room TBA)**		

See Modules for lecture templates, notes from class and supplementary materials