BME1452 Polymers for Biomedical Engineering

I. COURSE COMMUNICATION

Course Instructor: **Caitlin Maikawa (she/her)**
Contact: caitlin.maikawa@utoronto.ca

Course Meetings: Tuesdays 9:30 – 11:00 am SUB120
Thursdays 15:00-16:30 pm BA1220

Student Hours: TBD MB330

The course instructor is available to review course topics, provide help or clarification on homework problems, discuss course assignments, or talk about careers. We welcome both specific questions and more general requests for guidance on course topics. Please join even if you don't have any questions and just want to listen to the questions of others. If students seeking help have conflicts with the time above, please reach out to schedule an appointment, or send your questions by email.

Teaching Assistant: TBD
Contact:

Communication: We aim to respond to emails within one business day.
When sending emails to the teaching team, please begin the subject line with the course code followed by your subject (Ex. "BME1452 - Absence"). This helps us to keep track of your emails. When possible, it is helpful if you can cc the entire teaching team on emails to allow for the best response.

II. COURSE OVERVIEW

Course Description

Soft materials like polymers are powerful tools for biomedical engineering and have applications in drug delivery, regenerative medicine and biomedical devices. Polymer chemistry and structure can dictate material function and can be used to tune the way these materials interact with biological matter. This course introduces polymer material properties including rheology, gelation, solubility, and glassy phase transition in the context of designing materials for biomedical applications. Classes will alternate between lectures that focus on introducing these fundamental polymer concepts and discussion-based classes where we will explore the application of these concepts in innovative biomaterials in the literature.

Learning Outcomes

Upon completing this course through attending the lectures and completing the assignments and course projects, students will be able to:

1. Demonstrate knowledge of polymer material properties and design considerations
2. Compare and contrast polymer materials for use in different applications
3. Analyze and critique polymer materials design in the literature
4. Conceptually design biomaterials for a variety of biomedical applications
5. Identify methods to test and tune biomaterials
6. Communicate scientific ideas clearly

Course Materials:
No single textbook covers all of the material in a comprehensive manner for a diverse audience. All material will be provided in the course notes, handouts, and assigned journal articles. For those looking for supplemental reading I suggest:

Young, R.J., & Lovell, P.A. (2011). Introduction to Polymers (3rd ed.). CRC Press. https://doi.org/10.1201/9781439894156

Course Meetings and Expectations:
In this class, our goal is to provide students the knowledge and skills to apply course concepts to critique literature using polymer biomaterials. Class time will be devoted to key polymer materials concepts, discussion of biomaterials technologies, criticism of papers, and development of new ideas. To get the most out of this course, it is expected that students will do the assigned readings ahead of class and come to class prepared to engage with the material and their classmates. There will be two 1.5 hour meetings per week and there will be three types of meetings:

There are 3 class styles in the course:

Polymer Fundamentals: During these lecture-style meetings we will introduce key concepts of polymers.

Literature Discussions: In these sessions, students will take a deeper dive into papers in the literature relevant to course topics. Prior to class, students will be asked to read the paper and come to class prepared to discuss it. Small student teams will take turns providing an introductory presentation (15 min) to start the class off (students will present once during the semester). These presentations will introduce the biomedical application and challenge and may also provide explanation of key measurement techniques. For the remainder of class, students will breakout into discussion groups to discuss the materials used in the paper following provided discussion prompts. When quizzes are scheduled on Literature Discussion days, the first 20 minutes of class will be used for the quiz.

Mini-Design: In contrast to literature discussion sessions which are designed to go into depth on an example from the literature, mini-design sessions aim to give students broader exposure to different applications or approaches that exploit polymer properties. They will also require students to begin assessing the suitability of different approaches for specific applications through case study activities. For example, after introducing rheology, we will discuss bioinks for bioprinting. Students will be introduced to shear thinning hydrogels with physical crosslinks, jammed hydrogels, and in situ polymerization. Students will then be challenged to work together in small groups to assess the pros and cons of these different approaches in the framework of a short case study.

III.COURSE ASSESSMENT

Course Evaluation Plan:

Assignments (25 %)
- Mini-Design problem sets the top 7 out of 9 will count towards the grade (25%)

Quizzes (30%)
- Quizzes 10% each, top 3 out of 4 will count towards the grade

Presentations (10%)
- Literature discussion introduction

Proposal (35%)
- Proposal Outline: 10%
- Final Proposal: 25%

Assignment Details

Quizzes: There will be 4 quizzes throughout the term, and each quiz will count for 10%. Quizzes will focus on testing student's fundamental knowledge of course concepts.

> ***Quiz dates are listed on the course syllabus below and will take place at the start of literature discussions.***

Mini-design: As part of the small group discussions in class for the mini-design sessions, students will be asked to complete a short problem set that compares the different approaches discussed in class for the case study scenario, and suggest a materials design approach or measurement technique for materials. This will require students to identify key design criteria for the case study scenario, compare and contrast different materials approaches, and assess which approach may be most effective.

> ***Mini-design problem sets are expected to mostly be completed in class and will be due before the next class period on Quercus. Each group is responsible for submitting one copy for grading.***

Presentations: For each literature discussion class, a small group of students will be assigned to introduce the topic to the group. Each student will give one presentation during the course. This will be a short 10-15 minute presentation to give the class context on the biomedical challenge being addressed in the paper, and other strategies that have been used to address it before students break into discussion groups to discuss the polymer materials used in the paper.

> ***Due dates and groups will be assigned by the end of the first week of class.***

Proposal: Students will be asked to write a short research proposal (2 pages) about the development of a polymer materials technology for biomedical engineering applications, in the style of an NSERC CGS application. Students will choose one of the case studies from class to further develop for the proposal. The assignment will be split into two components, an outline and a final proposal. Students will receive feedback on the outline that they can incorporate into the final assignment.

> ***Proposal Outline: Due November 5***
> ***Final Proposal: Due December 4***

Late Policy and Absences:

Attendance is important to get the most out of this course as Literature Discussion and Mini-Design sessions are structured to promote in-class group learning. In general, flexibility has been worked into the grading structure to allow for no questions asked absences. If you have extenuating circumstances that will result in more absences, please speak to the teaching team in advance.

Literature Discussion Presentation: If there are conflicts with the assigned date, arrangements must be made well in advance (> 2 weeks) with the teaching team.

Mini-Design: Students will not receive a grade for Mini-Design assignments if they are absent from the associated class as the majority of the work is meant to occur during the class period. The top 7 out of 9 Mini-Design assignments will count towards the final grade. Late Mini-Design assignments will have a 10% late penalty applied for each day they are late.

Additional notes about attendance for Mini-Design: Mini-Design sessions missed for medical reasons (ex. extended illness) can be made up independently if medical documentation is provided. Hybrid attendance (i.e. via Zoom) is not allowed. Arriving more than 15 minutes late to class will count as an absence (ex. for a 9:40 am class, arriving after 9:55 am would count as an absence).

Proposal and Outline: Everyone will receive two free late days to be used for either the proposal or outline. This is a no questions asked extension for up to 48 hours after the due date. After this, a 10% late penalty will be applied each day unless accommodation or extensions were requested > 1 week in advance. (ex. a 1 day extension on the outline and a 1 day extension on the proposal, or an on-time outline and a 2 day extension on the proposal. Assignments will not be accepted if submitted more than 7 days after the original due date.

IV. COURSE SCHEDULE

PF: Polymer Fundamentals MD: Mini-Design LD: Literature Discussions

Week	Session 1 (1.5 h)	Papers for Literature Discussions
Sep. 2 Sep. 4	Course Introduction **PF:** Polymer concentrations and scaling at interfaces	
Sep. 9 Sep. 11	**MD:** Anti-fouling Coatings **LD:** Bottlebrush polymers	
Sep. 16 Sep. 18	**PF:** Polyelectrolytes **MD:** Layer-by-layer Assembly	Reineke *et al.* ACS Macro Lett. 10, 375–381 (2021)
Sep. 23 Sep. 25	**LD:** Swellable Microneedles, **Quiz 1** **PF:** Polymer Solubility	Karp *et al*. Nat Commun 4, 1702 (2013).
Sep 30 Oct. 2	**MD:** Thermo-responsive Materials **LD:** Self-folding microcapsules	
Oct. 7 Oct. 9	**PF:** Self-Assembly **MD:** Block-Copolymers	Ionov *et al*. Soft Matter, 2011,7, 3277-3279
Oct. 14 Oct. 16	**PF** Semi-conductive polymers **LD:** Soft electronics, **Quiz 2**	Bao *et al. ACS Cent. Sci. 2019, 5, 1884−1891*
Oct. 21 Oct. 23	**PF:** Polymer Synthesis **MD:** Polymer Characterization (Molecular Weight)	
Oct. 28 Oct .30	Reading Week – No Class	
Nov. 4 Nov. 6	**PF:** Rheology ***Proposal Outline is Due*** **MD:** Bioinks for 3D Bioprinting	
Nov. 11 Nov. 13	**LD:** Microrheology for soft and living materials, **Quiz 3** **PF:** Introduction to Gels and gelation	Heilshorn *et al.*, ***Soft Matter***, 2021,**17**, 1929-1939
Nov. 18 Nov. 20	**MD:** Tuning Diffusivity and Mesh Size **LD:** Sustained co-delivery	Appel *et al. ACS Cent. Sci.* 2020, 6, 10, 1800–1812
Nov. 25 Nov. 27	**MD:** Stimuli-responsive Materials **LD:** Photo-reversible patterning **Quiz 4**	**DeForest, C.A.*** & Tirrell, D.A. *Nature Materials*, **14**, 523-531 (2015).
Dec. 2 Dec. 3	**MD:** Affinity-directed materials ***Proposal Assignment is Due***	Webber *et al. ACS Cent. Sci.* 2019, 5, 6, 1035–1043

Lecture Topics:

Week 1: These initial lectures will give an overview of the course, the course expectations and assignments and an introduction to polymers and their applications in biomedical engineering. This will include discussing different polymer classification systems and how polymer structures can predict material properties (ex. Density, intermolecular forces, degradation rate).

Weeks 1-8: The first half of the course introduces topics in polymer physics and chemistry including polymer scaling, polymer thermodynamics, polyelectrolytes, self-assembly behaviour, semi-conductive polymers, and polymerization techniques.

Week 1-2: Polymer concentrations and scaling at interfaces. Polymer length scale varies in different solvents and when interacting with other polymers. In this lecture, students will be introduced to basic concepts in polymer physics, polymer scaling in different solvents, and polymer scaling at interfaces. This will lead into a mini-design session that continues to build on designing polymer coatings at interfaces based on scaling behaviour in the context of non-fouling coatings, and will conclude with a study of bottlebrush polymer design.

Weeks 3-4: Polyelectrolytes. Polyelectolyes are charged polymers and include DNA, RNA, and proteins as well as many common synthetic polymers. This lecture will focus on introducing how charge density and strength alters polymer scaling, and how this is related to polymer swelling behaviour. We will do a mini-design lesson on layer-by-layer material design and applications, and a literature discussion on swellable microneedles.

Weeks 4-5: Polymer Solubility. This lecture will introduce polymer thermodynamics, polymer phase separation, and lower and upper critical solution temperature. The following mini-design and literature discussion will focus on thermos-responsive polymers and how lower critical solution temperature can be used for in situ gelation and thermo-responsive drug carriers.

Week 6: Self-Assembly. This lecture will introduce polymer self-assembly behaviour and the types of microstructures that can be formed (i.e. micelles, lamellar structures, gyroid) with different polymer block lengths and properties. The mini-design component, will include further discussion of block copolymers, their design and applications in nanoparticles, as surfactants and surface modifiers, and application in disrupting cell membranes.

Week 7: Semi-conductive polymers. This lecture will introduce conductive polymers, and will build on the previous weeks topics of self-assembly to discuss crystalline and amorphous regions and the importance of connectivity in polymer conductivity. The literature discussion will look at applications of conductive polymers in soft electronics.

Week 8: Polymerization Techniques and Characterization. This lecture will introduce techniques for polymer synthesis including step growth, controlled radical polymerization. In the mini-design component, students will further compare and contrast different polymer characterization techniques.

Weeks 8-13: The second half of the courses focuses on bulk material properties and introduces rheology and its applications in both 3D bioprinting and for understanding cell-material interactions. The focus is then shifts to learning about polymer gels and how to engineer polymer cross-linking interactions for different functions including: tuning mesh size to control diffusivity of cargo, using stimuli-responsive chemistry to alter mesh size or degrade crosslinks, and affinity-interactions for dynamic cross links or controlled drug release.

Weeks 8-9: Rheology. The rheology lecture will introduce students to non-newtonian properties of polymers (i.e. shear-thinning, shear thickening), relaxation time, and viscoeleastic behaviour. The mini-design component will focus on polymer bioinks for 3D bioprinting and the rheological properties

necessary for a good bioink. This topic will finish with a literature discussion of microrheology and its use for studying cell-polymer interactions and viscoelastic properties on the cell-scale.

Weeks 10-13: Introduction to gels and gelation. The remaining weeks of the class will introduce gel and gelation properties, and then dive deeper into different types of cross-linking for material design. This will include discussion of degradable cross-links and photo-crosslinkable materials as well as affinity-based crosslinks and affinity interactions applied to drug delivery.

V. COURSE EXPECTATIONS

What you can expect from me:

I am here to guide your learning and will challenge you to actively engage in the learning process through class activities, assignments, and more. I will strive for an inclusive and collaborative classroom—one that is respectful of gender, disability, age, race, and all other dimensions of diversity and identity, as well as each person's unique circumstances at this time. I will do my best to give you the tools, feedback, and support to succeed, and will always welcome suggestions for improvement. Learning is a never-ending process, so I hope to motivate students to seek out more information on topics we don't have time to cover. I highly encourage everyone to visit me in office hours or to set up a meeting, even if you don't feel that you have questions. I want to get to know you and support you in this learning experience! The best way to reach me is by email (see contact information) and you can expect me to respond within 24 hours.

What I expect from you:

Each week, a new module will be released on Quercus, and you are expected to do the required readings, participate in class discussions, and submit any assignments according to the deadlines. Announcements will be made on Quercus, so please check the website regularly for updates. It can be easy to get distracted during meetings. I ask that you try as best as you can to remain focused and engaged during class and try to keep distractions from technology to a minimum (closing email and turning off notifications helps!). I expect you to take an active role in your learning by coming to our class meetings prepared and ready to collaborate with your classmates. Keep in mind that each member of this class has different ideas and perspectives that will enrich the experience for us all. I expect all of us to speak and listen with compassion and not make assumptions about others. As noted in university policy, I expect what happens in class to stay in class, to protect the privacy of class members and other rights of the university. It is recommended students attend all course meetings, if possible. Students are encouraged to additionally attend the student hours. If the student is unable to attend the times designated by the instructor or course assistants, please email to schedule an appointment. This class should challenge you, but I believe everyone has the ability to succeed with some effort.

Policies and Statements

University Land Acknowledgement

I wish to acknowledge this land on which the University of Toronto operates. For thousands of years, it has been the traditional land of the Huron-Wendat, the Seneca, and the Mississaugas of the Credit. Today, this meeting place is still the home to many Indigenous people from across Turtle Island and we are grateful to have the opportunity to work, learn, and conduct our research on this land.

Learn more about Canada's relationship with Indigenous Peoples here.

Indigenous Students' Supports
If you are an Indigenous engineering student, you are invited to join a private Discord channel to meet other Indigenous students, professors, and staff, chat about scholarships, awards, work opportunities, Indigenous-related events, and receive mentorship. Email Professor Bazylak or Darlee Gerrard if you are

interested.

Indigenous students at U of T are also invited to visit First Nations House's (FNH) Indigenous Student Services for culturally relevant programs and services. If you want more information on how to apply for Indigenous specific funding opportunities, cultural programs, traditional medicines, academic support, monthly social events or receive the weekly newsletter, go to the FNH website, email or follow FNH on social media: Facebook, Instagram, or TikTok. A full event calendar is on the CLNX platform. Check CLNX often to see what new events are added!

Wellness and Mental Health Support

As a university student, you may experience a range of health and/or mental health challenges that could result in significant barriers to achieving your personal and academic goals. The University of Toronto and the Faculty of Applied Science & Engineering offer a wide range of free and confidential services that could assist you during these times.

As a U of T Engineering student, you have a Departmental Undergraduate Advisor or a Departmental Graduate Administrator who can support you by advising on personal matters that impact your academics. Other resources that you may find helpful are listed on the U of T Engineering Mental Health & Wellness webpage, and a small selection are also included here:

- U of T Engineering's Mental Health Programs Officer
- Accessibility Services & the On-Location Advisor
- Health & Wellness and the On-Location Health & Wellness Engineering Counsellor
- Graduate Engineering Council of Students' Mental Wellness Commission
- SKULE Mental Wellness
- U of T Engineering's Learning Strategist and Academic Success
- Registrar's Office and Scholarships & Financial Aid Office & Advisor

We encourage you to access these resources as soon as you feel you need support; no issue is too small.

If you find yourself feeling distressed and in need of more immediate support, consider reaching out to the counsellors at U of T Telus Health Student Support or visiting U of T Engineering's Urgent Support – Talk to Someone Right Now.

Accommodations

Students with diverse learning styles and needs are welcome in this course. The University of Toronto supports accommodations for students with diverse learning needs, which may be associated with mental health conditions, learning disabilities, autism spectrum, ADHD, mobility impairments, functional/fine motor impairments, concussion or head injury, visual impairments, chronic health conditions, addictions, D/deaf, deafened or hard of hearing, communication disorders and/or temporary disabilities, such as fractures and severe sprains, or recovery from an operation.

If you have a learning need requiring an accommodation the University of Toronto recommends that students register with Accessibility Services as soon as possible.

We know that many students may be hesitant to reach out to Accessibility Services for accommodations. The purpose of academic accommodations is to support students in accessing their academics by helping to remove unfair disadvantages. We can assess your situation, develop an accommodation plan with you, and support you in requesting accommodation for your course work. The process of accommodation is private; we will not share details of your needs or condition with any instructor.

If you feel hesitant to register with us, we encourage you to reach out for further information and resources on how we can support. It may feel difficult to ask for help, but it can make all the difference during your time here.

Phone: 416-978-8060
Email: accessibility.services@utoronto.ca

Equity, Diversity and Inclusion

Looking for community? Feeling isolated? Not being understood or heard?

You are not alone. You can talk to anyone in the Faculty that you feel comfortable approaching, anytime – professors, instructors, teaching assistants, first-year or upper years academic advisors, student leaders or the Assistant Dean of Diversity, Inclusion and Professionalism.

You belong here. In this class, the participation and perspectives of everyone is invited and encouraged. The broad range of identities and the intersections of those identities are valued and create an inclusive team environment that will help you achieve academic success. You can read the evidence for this approach here.

You have rights. The University Code of Student Conduct and the Ontario Human Rights Code protect you against all forms of harassment or discrimination, including but not limited to acts of racism, sexism, Islamophobia, antisemitism, homophobia, transphobia, ableism, classism and ageism. Engineering denounces unprofessionalism or intolerance in language, actions or interactions, in person or online, on- or off-campus. Engineering takes these concerns extremely seriously and you can confidentially disclose directly to the Assistant Dean for help here.

Resource List:

- Engineering Equity, Diversity & Inclusion Groups, Initiatives & Student Resources
- Engineering Positive Space Resources
- Request a religious-based accommodation here
- Email Marisa Sterling, P.Eng, the Assistant Dean, Diversity, Inclusion & Professionalism here
- Make a confidential disclosure of harassment, discrimination or unprofessionalism here or email engineering@utoronto.ca or call 416.946.3986
- Email the Engineering Society Equity & Inclusivity Director here

U of T Equity Offices & First Nations House Resources