Annexe A: New/Revised Course Content in OBTL+ Format

Course Overview

Expected Implementation in Academic Year	AY2025-2026
Semester/Trimester/Others (specify approx. Start/End date)	Semester 2
Course Author * Faculty proposing/revising the course	Han Endao
Course Author Email	endao.han@ntu.edu.sg
Course Title	Signal and noise in biology
Course Code	PH3408/MH3401
Academic Units	3
Contact Hours	39
Research Experience Components	Not Applicable

Course Requisites (if applicable)

Pre-requisites	MH1100 Calculus I and MH1101 Calculus II or MH1802 Calculus for the Sciences or BS1008 Biostatistics and MH1101 Calculus II
Co-requisites	
Pre-requisite to	
Mutually exclusive to	
Replacement course to	
Remarks (if any)	

Course Aims

At the interface between biology, physics, and engineering, there is a wild frontier waiting to be explored. Over recent years, an increasing number of researchers with math or physics backgrounds have developed interests in biology-related topics. Concurrently, biological research is becoming more quantitative, and data driven. The world needs a new generation of biologists equipped with skills in mathematical modeling, data processing, and coding. The aim of this course is to introduce quantitative biology using a diverse range of phenomena related to signal and noise in biological systems as examples. You will learn some basic yet essential mathematical techniques and discover how these tools further our understanding of biology and biophysics. If you are a physics or math major interested in biology but haven't been trained in it, this course is perfect for you. If you are a biology or engineering major with basic knowledge in calculus and statistics, this course is also ideal. Join us and position yourself at the forefront of a transformative movement toward interdisciplinary research.

Course's Intended Learning Outcomes (ILOs)

Upon the successful completion of this course, you (student) would be able to:

ILO 1	Apply fundamental concepts and techniques in statistics to describe various biological processes and solve problems in quantitative biology.
ILO 2	Describe the central dogma in biology and relevant properties of DNA, RNA, and proteins.
ILO 3	Describe basic mechanism of kinetic proofreading.
ILO 4	Connect different phenomena related to stochastic gene expression.
ILO 5	Conclude that stochasticity is an important feature in biology.
ILO 6	Describe physics that govern bacterial motility.
ILO 7	Explain the physics principles behind molecule counting, chemotaxis, and development.
ILO 8	Apply simple differential equations and non-linear dynamics to model and describe biological systems.
ILO 9	Describe how signals are initiated, propagated and decided to proceed forward in neuronal axon.
ILO 10	Describe the mechanism that makes chemotaxis and other biological processes robust.
ILO 11	Describe all-or-none phenomena in biology.
ILO 12	Implement principles of information theory in biology.
ILO 13	Utilize efficient representation in biological contexts.

Course Content

Basic statistics, different distributions, and some of their applications in biology.

Basic knowledge in molecular biology.

Stochasticity in biochemistry

- Kinetic proofreading
- Stochastic gene expression

Molecule counting

- Motility and chemotaxis in bacteria
- Signals in development

Control

- Differential equations and non-linear dynamics
- Signal and noise in neurobiology
- Robustness of chemotaxis
- All-or-none phenomenon

Integration of signal and noise in neurobiology

- Information theory
- Efficient representation

Reading and References (if applicable)

- Recommended papers on relevant topics.
- Biophysics: Searching for Principles by William Bialek, Princeton University Press, 2012. ISBN 978069113891.
- Physical Models of Living Systems (Second Edition) by Philip Nelson, Chiliagon Science, 2007. ISBN 978-1-7375402-4-3.
- Nonlinear Dynamics and Chaos by Steven H. Strogatz. Westview Press, 2014. ISBN 978-0738204536.
- Introduction to Molecular Biophysics (1st Edition) by Jack A. Tuszynski and Michal Kurzynski, CRC Press, 2020. ISBN 9780367578541.

NOTE: The above listing comprises the foundational readings for the course and more up-to-date relevant readings will be provided when they are available.

Planned Schedule

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
1	Introduction	1	Lecture notes and paper: • Crick, F. 1970. Central Dogma of Molecular Biology. Nature 227, 561–563.	In-person	
2	Statistics	1	Lecture notes.	In-person	Assignment 1.
3	Kinetic proofreading	2	Lecture notes and paper: • Hopfield JJ. 1974. Kinetic proofreading: a new mechanism for reducing errors in biosynthetic processes requiring high specificity. PNAS 71:4135-9 • Zaher HS, Green R. Fidelity at the molecular level: lessons from protein synthesis. Cell. 2009 Feb 20;136(4):746-62. • Demeshkina, N., Jenner, L., Westhof, E. et al. A new understanding of the decoding principle on the ribosome. Nature 484, 256–259 (2012).	In-person	Tutorial 1
4	Stochastic gene expression	3, 4, 5	Lecture notes and papers: • Santillán M, Mackey MC. 2008. Quantitative approaches to the study of bistability in the lac operon of Escherichia coli. J R Soc Interface. 5 Suppl 1(Suppl 1):S29-39. • Elowitz MB, Levine AJ, Siggia ED, Swain PS. 2002. Stochastic gene expression in a single cell. Science 297: 1183-6. • Yu J et al. 2006. Probing Gene Expression in Live Cells, One Protein Molecule at a Time. Science 311:1600-3.	In-person	Assignment 2.
5	Motility and chemotaxis in bacteria	6, 7	Lecture notes and paper: • Purcell EM. 1977. Life at low Reynolds number. American Journal of Physics 45, 3–11.	In-person	Tutorial 2.
6	Chemotaxis and signals in development	7	Lecture notes.	In-person	Assignment 3.
7	Mid-term test	1 - 7		In-person	Tutorial 3.

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
8	Differential equations and non-linear dynamics	8	Lecture notes.	In-person	
9	Signal and noise in neurobiology	9	Lecture notes and paper: • Alon U et al. 1999. Robustness in bacterial chemotaxis. Nature 397:168-71.	In-person	Assignment 4.
10	Robustness	10	Lecture notes and paper: - Alon U et al. 1999. Robustness in bacterial chemotaxis. Nature 397:168-71.	In-person	Tutorial 4.
11	All-or-none phenomenon	11	Lecture notes and paper: - Novick A, Wiener M. 1957. Enzyme induction as an all-or-none phenomenon PNAS 43:553-66.	In-person	Tutorial 4
12	Information theory	12	Lecture notes	In-person	Assignment 5
13	Efficient representation	13	Lecture notes and paper: - Laughlin SB. 1981. A simple coding procedure enhances a neuron's information capacity. Z. Naturforsch. 36:910-12.	In-person	Tutorial 5

Learning and Teaching Approach

Approach	How does this approach support you in achieving the learning outcomes?
Lectures	Learn the fundamental knowledge, principles, and techniques related to the topics listed above.
Problem solving (tutorial and lecture)	Develop competence in applying the principles and techniques learned to solve biology-related problems quantitatively.
Hands-on group coding session (during tutorial)	Write codes to solve biological problems. You are encouraged to work in groups and discuss with your classmates.

Assessment Structure

Assessment Components (includes both continuous and summative assessment)

No.	Component	ILO	Related PLO or Accreditation	Weightage	Description of Assessment Component	Team/Individual	Rubrics	Level of Understanding
1	Summative Assessment (EXAM): Final exam(Final Examination)	All		50		Individual	Analytic	Extended Abstract
2	Continuous Assessment (CA): Assignment(Continuous Assessment 1 (CA1): Problem sets)	All		25		Individual	Analytic	Extended Abstract
3	Continuous Assessment (CA): Test/Quiz(CA2: Mid-term test)	1 to 7		25		Individual	Analytic	Extended Abstract

Description of Assessment Components (if applicable)

Problem sets
We will have five problem sets/assignments in total. Each assignment constitutes 5% in your final score, so the five assignments will be 25% in total. We will release the assignment as indicated in Planned Schedule. When the assignments have been graded, the feedback will be provided during the corresponding tutorial sessions. You can work individually or as a part of a team, but everyone's assignment must be submitted individually. You are supposed to submit the assignments on time.

Midterm Examination
The midterm examination will be an individual assessment covering the course topics in lectures 1 to 7. The exam has two parts: mandatory part and optional part. You need to answer all the questions in the mandatory part and select any 1 out of 2 questions to answer from the optional part. If you answer all 2 questions in the optional part, we will select the one question with the highest score. The exam will consist of at least one essay-type question that require you to demonstrate a comprehensive understanding of the material, synthesize information from various topics, and apply concepts to new contexts. This exam will be held in week 8, and it will constitute 25% of your overall course grade.

Final Examination
The final examination will be an individual assessment covering all course topics. The exam has two parts: mandatory part and optional part. You need to answer all the questions in the mandatory part and select any 2 out of 3 questions to answer from the optional part. If you answer all 3 questions in the optional part, we will select the two questions with the highest scores. The exam will consist of at least one essay-type question that require you to demonstrate a comprehensive understanding of the material, synthesize information from various topics,

and apply concepts to new contexts. This exam will be held during the exam week, and it will constitute 50% of your overall course grade.

Formative Feedback

You will receive formative feedback through discussion within classes and tutorial lessons. Each homework will be scored and returned to you for review. Feedback is also given after the midterm on the common mistakes and level of difficulty of the problems. Discussions with me in person or via email are always welcome.

NTU Graduate Attributes/Competency Mapping

This course intends to develop the following graduate attributes and competencies (maximum 5 most relevant)

Attributes/Competency	Level
Creative Thinking	Advanced
Curiosity	Advanced
Learning Agility	Advanced
Problem Solving	Advanced
Transdisciplinarity	Advanced

Course Policy

Policy (Academic Integrity)

Good academic work depends on honesty and ethical behaviour. The quality of your work as a student relies on adhering to the principles of academic integrity and to the NTU Honour Code, a set of values shared by the whole university community. Truth, Trust and Justice are at the core of NTU's shared values. As a student, it is important that you recognize your responsibilities in understanding and applying the principles of academic integrity in all the work you do at NTU. Not knowing what is involved in maintaining academic integrity does not excuse academic dishonesty. You need to actively equip yourself with strategies to avoid all forms of academic dishonesty, including plagiarism, academic fraud, collusion and cheating. If you are uncertain of the definitions of any of these terms, you should go to the academic integrity website for more information. On the use of technological tools (such as Generative AI tools), different courses / assignments have different intended learning outcomes. Students should refer to the specific assignment instructions on their use and requirements and/or consult your instructors on how you can use these tools to help your learning. Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.

Policy (General)

You are expected to attend all lectures punctually and take all scheduled assignments and tests by due dates. You are expected to take responsibility to follow up with course notes, assignments and course related announcements for lectures you have missed. You are expected to participate in all tutorial sessions.

Policy (Absenteeism)

If you are sick and unable to attend your class / Mid-terms, you have to:
1. Send an email to the instructor regarding the absence.
2. Submit the Medical Certificate* or official letter of excuse to administrator.
3. Request for a make-up mid-term and attend the assigned make-up mid-term.

* The medical certificate mentioned above should be issued in Singapore by a medical practitioner registered with the Singapore Medical Association.

Policy (Others, if applicable)

Diversity and inclusion policy

Integrating a diverse set of experiences is important for a more comprehensive understanding of science.

It is our goal to create an inclusive and collaborative learning environment that supports a diversity of perspectives and learning experiences, and that honours your identities; including ethnicity, gender, socioeconomic status, sexual orientation, religion or ability.

To help accomplish this:
- If you are neuroatypical or neurodiverse, have dyslexia or ADHD (for example), or have a social anxiety disorder or social phobia;
- If you feel like your performance in the class is being impacted by your experiences outside of class;
- If something was said in class (by anyone, including the instructor) that made you feel uncomfortable;

Please speak to your teaching team, our school pastoral officer or a peer or senior (either in-person or via email) about how we can help facilitate your learning experience.

As a participant in course discussions, you should also strive to honour the diversity of your classmates. You can do this by: using preferred pronouns and names; being respectful of others opinions and actively making sure all voices are being heard; and refraining from the use of derogatory or demeaning speech or actions.

All members of the class are expected to adhere to the NTU anti-harassment policy. if you witness something that goes against this or have any other concerns, please speak to your instructors or a faculty member.