BME-470/770 | COURSE OUTLINE

Computational Cardiology

Course code	BME-470/770 (undergraduate section BME-470; graduate section BME-770)
Credit hours	3 (2 + 1): two lecture hours and one three-hour laboratory per week
Levels	BS (final year) | MS | PhD — one course, three levels of assessment
Prerequisites	Ordinary and partial differential equations; numerical methods; linear algebra; introductory physiology; programming in MATLAB or Python.
Instructor	Dr. Asif Mehmood, Department of Biomedical Engineering and Computer Science
Contact	asifnazquaidian@gmail.com
Delivery	Lectures with derivations, weekly simulation laboratory, graduate research project
Textbook	Computational Cardiology: Multiscale models of the heart, from ion channels to digital twins: electrophysiology, mechanics, circulation, uncertainty and machine learning (course textbook, October 2026), with the reference books below.

1 Course description

Computational cardiology builds mathematical and computational models of the heart to explain its function, predict the effects of disease, drugs and devices, and personalise therapy. This course follows the heart up its scales. It starts from cardiac cellular electrophysiology for modellers and the numerical methods that stiff cardiac models demand, then develops ionic models from Noble (1962) and Luo–Rudy to the human ventricular models used today in regulatory drug-safety testing, and phenomenological models of restitution and alternans. It derives the monodomain and bidomain equations of cardiac tissue, studies propagation, re-entry, spiral waves and defibrillation, and computes the electrocardiogram by solving the forward problem and the regularised inverse problem. It then couples electrophysiology to mechanics and the circulation through time-varying elastance and Windkessel models. The final part addresses calibration, uncertainty quantification and patient-specific modelling, machine learning and physics-informed neural networks in cardiology, and the credibility, regulation and clinical translation of cardiac digital twins. Undergraduates master the models and simulations; master's and doctoral students add derivations, numerical analysis, the primary literature and a research project.

2 Course learning outcomes (CLOs)

Outcomes are written at the cognitive levels of Bloom's revised taxonomy and mapped to the programme learning outcomes (PLOs) of the host programme (for engineering degrees, the Washington Accord graduate

CLO	Students will be abl
CLO1	Formulate cardiac cel physiological princip assumptions.
CLO2	Implement cardiac m numerical methods a
CLO3	Analyse restitution, a and the ECG with mo arrhythmia mechanis
CLO4	Couple electrophysio models and interpret
CLO5	Calibrate models to d evaluate model credib use.
CLO6	Design, carry out and computational-cardio validation and uncert

attributes used by PEC; for computing degrees, the Seoul Accord attributes used by NCEAC).

3 Weekly schedule

Sixteen weeks: fourteen teaching weeks, a mid-term week and a final-examination week. Each teaching week has two lecture hours and one three-hour computational laboratory.

Week	Topic (textbook chapter)	Laboratory	Assessment / CLO
1	Computational Cardiology and the Cardiac Digital Twin (Ch. 1)	A first cardiac model	Diagnostic quiz
2	Cardiac Cellular Electrophysiology for Modellers (Ch. 2)	Gates under voltage clamp	Problem set 1 (CLO1)
3	Numerical Methods for Stiff Cardiac Models (Ch. 3)	Forward Euler versus Rush–Larsen	Lab report 1 (CLO2)
4	Ionic Models I: From Noble to Luo–Rudy (Ch. 4)	The Luo–Rudy 1991 model	Lab report 2 (CLO1, CLO2)
5	Ionic Models II: Human Ventricular Models, Drug Safety and Populations (Ch. 5)	A population of models	Problem set 2 (CLO1)
6	Phenomenological Models, Restitution and Alternans (Ch. 6)	Restitution and alternans in the Mitchell–Schaeffer model	Lab report 3 (CLO3)
7	Cardiac Tissue: the Bidomain and Monodomain Equations (Ch. 7)	Propagation and conduction velocity	Quiz 1 (CLO1–CLO3); project proposal (graduate)
8	**Mid-term examination (Chapters 1–7)**	–	Mid-term (CLO1–CLO3)
9	Re-entry, Spiral Waves and Defibrillation (Ch. 8)	Spiral waves in two dimensions	Lab report 4 (CLO3)
10	The Forward and Inverse Problems of Electrocardiography (Ch. 9)	Pseudo-ECG and Tikhonov inversion	Problem set 3 (CLO3)

Week	Topic (textbook chapter)	Laboratory	Assessment / CLO
11	Cardiac Mechanics and the Pressure–Volume Loop (Ch. 10)	A time-varying elastance ventricle	Lab report 5 (CLO4)
12	The Circulation: Windkessel and Closed-Loop Models (Ch. 11)	Windkessel models	Problem set 4 (CLO4)
13	Calibration, Sensitivity and Uncertainty Quantification (Ch. 12)	Sensitivity analysis and a Gaussian-process emulator	Lab report 6 (CLO5)
14	Machine Learning and Physics-Informed Neural Networks in Cardiology (Ch. 13)	A neural-network surrogate	Quiz 2 (CLO4, CLO5)
15	Clinical Translation, Credibility and Cardiac Digital Twins (Ch. 14)	A virtual cohort and a decision	Project presentations (CLO6)
16	**Final examination (all chapters)**	–	Final (CLO1–CLO5); project report (CLO6)

4 Assessment

Undergraduate (BS) and graduate (MS/PhD) students attend the same lectures but are assessed differently: graduate students complete the advanced (MS) and research (PhD) exercises and a research project.

BS students

Problem sets (4)	15%
Quizzes (2)	10%
Laboratory reports (6)	20%
Mid-term examination	20%
Final examination	35%

MS and PhD students

Problem sets with MS/PhD problems	10%
Laboratory reports (6)	15%
Critical review of two research papers	10%
Mid-term examination	15%
Research project (proposal, presentation, report)	25%
Final examination	25%

Graduate research project

Graduate students choose a project in week 7 and present it in week 15. A project poses a mechanistic question and answers it with a verified model, with uncertainty quantification where relevant. Examples: in-silico assessment of the proarrhythmic risk of a drug from its channel-block profile with a population of human ventricular models; conditions for spiral-wave break-up in a two-dimensional tissue model; the pseudo-ECG of a one-dimensional fibre with transmural heterogeneity; calibration of a Windkessel model to a patient's pressure waveform with a Gaussian-process emulator; a physics-informed neural network for activation maps. Deliverables: a two-page proposal, a 15-minute presentation and a report in journal format (6–8 pages) with code and a verification section. PhD reports must state a hypothesis, include uncertainty analysis and compare with the literature.

Grading rubric for laboratory reports and projects

Criterion	Excellent (4)	Satisfactory (2–3)	Needs work (0–1)
Model and method	Correct equations, algorithms and parameters, justified choices	Minor errors that do not change conclusions	Wrong model or unexplained method
Code and results	Runs, reproducible, figures labelled with units, baselines and error bars	Runs with small gaps	Does not run or results missing
Interpretation	Links results to theory, physiology or the literature	Describes results without depth	No interpretation
Communication	Clear structure, correct references	Understandable, some gaps	Unclear or unreferenced

5 Reading list

Course textbook

Computational Cardiology: Multiscale models of the heart, from ion channels to digital twins: electrophysiology, mechanics, circulation, uncertainty and machine learning. Dr. Asif Mehmood, October 2026.

Reference books and papers

1. A. C. Guyton and J. E. Hall, *Textbook of Medical Physiology*, 11th ed. Elsevier Saunders, 2006 (Chapters 9–15, 20–22).
2. J. Keener and J. Sneyd, *Mathematical Physiology*, 2nd ed. Springer, 2009 (the heart and the circulation).
3. J. Sundnes *et al.*, *Computing the Electrical Activity in the Heart.* Springer, 2006; A. J. Pullan, M. L. Buist and L. K. Cheng, *Mathematically Modelling the Electrical Activity of the Heart.* World Scientific, 2005.
4. E. M. Izhikevich, *Dynamical Systems in Neuroscience.* MIT Press, 2007 (excitability and phase-plane methods, Chapters 3–7).
5. S. A. Niederer, J. Lumens and N. A. Trayanova, Computational models in cardiology, *Nat. Rev. Cardiol.* 16:100–111, 2019; R. H. Clayton *et al.*, Models of cardiac tissue electrophysiology, *Prog. Biophys. Mol. Biol.* 104:22–48, 2011.
6. Primary model papers: Noble (1962), Luo and Rudy (1991, 1994), ten Tusscher and Panfilov (2006), O'Hara *et al.* (2011), Aliev and Panfilov (1996), Mitchell and Schaeffer (2003), Fenton and Karma (1998), Suga and Sagawa (1974), Westerhof *et al.* (2009).
7. Credibility and translation: ASME V&V 40 (2018); FDA guidance on computational modelling (2023); Corral-Acero *et al.* (2020); Sel *et al.* (2024).

6 Course policies

- Attendance of at least 80% of lectures and laboratories is required to sit the final examination.

- Laboratory reports are individual work; code may be discussed but must be written and understood by the student; all sources, including AI assistants, must be acknowledged.
- Every simulation result must be accompanied by evidence of numerical convergence (time-step or mesh refinement).
- Late submissions lose 10% per day and are not accepted after five days without a documented reason.
- Plagiarism is handled according to the institution's academic-integrity policy and the HEC plagiarism policy.