

Academic Year of Degree: 2025/26

22135 - Organs and Systems Modelling

Teaching Guide Information

Academic Course: 2025/26

Academic Center: 337 - Engineering School

Study: 3378 - Bachelor's degree in Biomedical Engineering

Subject: 22135 - Organs and Systems Modelling

Credits: 4.0

Course: 3

Teaching languages:

Theory: Group 1: Spanish

Practice: Group 101: English

Group 102: English

Seminar: Group 101: English

Teachers: Andy Luis Olivares Miyares

Teaching Period: First term

Presentation

“Modelling of Organs and Systems” is a mandatory subject of the 3rd year of the Biomedical Engineering Bachelor’s degree at the Universitat Pompeu Fabra (UPF), taking place during the 1st trimester, from September to December. The duration of the subject corresponds to 4 ECTS credits.

The main goal of the subject is to **cover the most relevant computational steps in a patient-specific multi-scale modelling workflow**, going from three-dimensional patient-specific structural and functional data to personalized biophysical simulations that can help on better understanding the complexity of human systems. Biomedical data of organs and systems has a multi-scale nature across wide ranges of length (including genes, proteins, cells, tissues and organs) and time scales (from microseconds to human lifetime).

Multi-scale modelling of biological systems requires the development of mathematical and engineering tools that can describe in a realistic way the structure and function of the different components of the system and integrated them into a common reference at reasonable computational times. Some of these tools include images and signal processing algorithms (including machine learning techniques), meshing, numerical techniques for solving ordinary and partial differential (ODE, PDE) systems of equations, high-performance computing and validation/verification tools, among others. In this subject the most common of these techniques available nowadays will be presented in lecture sessions. Application to particular human body systems will be the focus of seminars and lab sessions.

Keywords: Principles of mathematical modelling; multi-scale biophysical modelling; finite-

element methods; meshing; parameter estimation; verification and validation; high-performance computing

Associated skills | General learning outcomes

Basic competences:

CB1. That the students have proved to possess and understand knowledge in a study area which comes from the basis of general secondary education, and is usually in a level which, although it is supported on advanced text books, it also includes some aspects which imply knowledge coming from their study field's innovation;

CB2. That the students can apply their knowledge to their work or vocation in a professional way and possess the competences which are usually proved by means of the elaboration and defense of arguments and solving of problems within their study area;

CB3. That the students have the ability of collecting and interpreting relevant data (normally within their study area) to pass judgements which include a reflection about relevant topics of social, scientific or ethical nature;

CB4. That the students can transmit information, ideas, problems and solutions to a public both specialized and non specialized;

CB5. That the students have developed those learning abilities necessary to undertake later studies with a high degree of autonomy.

Transversal competences

CT1. Working in group in international and interdisciplinary contexts.

CT2. Applying leadership and coordination and proving initiative.

CT3. Applying with flexibility and creativity the acquired knowledge and adapting it to new contexts and situations.

CT4. Communicating in academic and professional contexts in English, both orally and in writing

CT5. Generating new ideas and incorporating them in their daily work.

Specific competences

CE1. Solving the mathematical problems which arise in engineering and applying knowledge on: linear algebra; differential and integral calculus; numerical methods, numerical algorithms, statistics and optimization.

- RA.CE1.1 Apply linear algebra knowledge to solve problems in engineering
- RA.CE1.2 Show knowledge of differential and integral calculus to solve problems in engineering.
- RA.CE1.3 Use knowledge of numerical methods to solve problems in engineering.
- RA.CE1.4 Show knowledge of numerical algorithms to solve problems in engineering.
- RA.CE1.5 Use knowledge of statistics to solve problems in engineering.
- RA.CE1.6 Apply knowledge of optimization to solve problems which can arise in engineering.

CE3. Mastering the basic concepts of discrete mathematics, logic, algorithms and computational

complexity, and its application for solving typical problems in engineering.

- RA.CE3.1 Apply knowledge of discrete mathematics to solve problems in engineering.
- RA.CE3.2 Use knowledge of algorithms and computational complexity to solve problems in engineering.

CE4. Mastering the use and programming of computers, operating systems, databases and computer programs with application in engineering.

- RA.CE4.1 Master the basic and practical knowledge on the use and programming of computers with application in engineering.
- RA.CE4.2 Manage in a practical way the functionalities of operating systems.
- RA.CE4.3 Apply the features, functionalities and structure of databases which allow their proper use.

CE5. Recognizing the structure, organization, functioning and interconnection of computing systems, foundations of their programming, and knowing how to apply this knowledge for solving typical problems of engineering.

- RA.CE5.1 Recognize the structure, organization, functioning and interconnection of computing systems, as well as the foundations of their programming.
- RA.CE5.2 Solve problems in engineering applying knowledge related to the structure and programming of computing systems.

CE8. Developing computational methods for the solution of physical methods formulated in a continuous or discrete way.

- RA.CE8.1 Understand the principles of computational methods used in physical models.
- RA.CE8.2 Implement computational methods to solve physic models formulated in a continuous or discrete way.

CE9. Designing and implementing technological solutions related to the acquisition, processing, modelling, visualization and interpretation of biological, physiological and clinical variables and signals that contribute in the processes of prevention, diagnosis, treatment and rehabilitation.

- RA.CE9.1. Develop techniques of computational analysis of multimodal signals and images with applications in diagnosis and monitoring.
- RA.CE9.2 Design technological solutions related to the acquisition, processing, modelling, visualization and interpretation of biological, physiological and clinical variables and signals that contribute in the processes of prevention, diagnosis, treatment and rehabilitation.
- RA.CE9.3 Compare the several techniques and systems of acquisitions of biomedical signals and images capable of providing information and/or functional information of the several biological and physiological processes.
- RA.CE9.6 Building computational models for the simulation of treatments of osteomuscular diseases.

CE10. Designing and implementing computational tools to study biological systems human physiology with an integrated focus.

- RA.CE10.1 Create computational tools to study biological systems.
- RA.CE10.2 Design computational tools to study human physiology
- RA.CE10.3 Propose computational tools to study biological systems and human physiology with an integrated focus

- RA.CE10.4 Recognizing the fundamental engineering elements and tools related to biological elements at different scale
- RA.CE10.6 Applying computational techniques in the field of cardiology.

CE11. Recognizing the main physiopathological mechanisms for the computational modelling of the human body's several organic systems, with emphasis in the cardiovascular system, the nervous system and locomotive system, incorporating notions of multiscale modelling and systems physiology.

- RA.CE11.1 Use knowledge on the main physiopathological mechanisms to computationally model the several organic system of the human body's, with emphasis in the cardiovascular system, the nervous system and locomotive system, incorporating notions of multiscale modelling and systems physiology.
- RA.CE11.2 Apply computational models of human physiology and their personalization by explorations and clinical information for the planning of minimally invasive treatments.

Learning outcomes | Specific learning outcomes

Understand the main mechanisms and computationally model the various organs and systems of the human body.

Apply computational models of human physiology and their personalization through clinical information.

Analysis of the structure and function of human organs and systems, and their most relevant alterations

Analyze and relate the biological foundations of the structure and function of human beings, and the molecular and cellular bases of diseases.

Contents

Theoretical Content

The theoretical content of this course will cover the most methodological aspects of the entire modeling process, leaving the application part for seminars and lab sessions.

Lectures

Module 1. Modeling of organs and systems in biomedicine (1.5 lectures)

Principles of mathematical modeling. Multiscale modeling workflow. Systems modeling. Examples of biophysical modeling: fluid simulations of left atrial appendage occluder devices.

Module 2. Mesh generation (0.5 lectures)

Patient-specific meshes. Geometry concepts. Marching cubes. Structured and unstructured meshing algorithms. Remeshing. Quality metrics. Meshless methods.

Module 3. Software demonstration (2 lectures)

Demonstration of different software used in a modeling pipeline, including CAD software, solvers (Ansys Fluent, LS-Dyna, others), and Paraview.

Module 4. Boundary conditions (1 lecture)

Concept of boundary conditions, inlets/outlets. Lumped hemodynamic models. Analogies between electrical circuits and flow properties. Boundary conditions (Windkessel).

Module 5. Numerical techniques (2 lectures)

Finite differences. Finite elements. Transient advection-diffusion. Computational fluid dynamics (CFD).

Module 6. Verification and validation (1 lecture)

VVUQ (Verification, Validation, Uncertainty Quantification). Convergence and stability. Mesh resolution independence, error sources. Phantoms. Experimental models. Tissue experiments. Inverse problems.

Seminars

Seminar 1. Segmentation and computer-aided design (CAD) tools

Tutorials for medical image segmentation.

Seminar 2. Meshing tools

Tutorials and examples using mesh format converters, Meshmixer, Gmsh, Meshlab, and Blender, among others.

Seminars 3–4. Multiphysics numerical solvers

Tutorials and examples using ANSYS (Fluent and LS-Dyna).

Seminar 5. Visualization of anatomical models and simulation results

Tutorials and examples using Paraview.

Detailed Activity Plan

The activity plan, specifying sessions and weekly deliverables, is detailed below:

Week 1:

Lecture sessions L1 (Intro-I), L2 (Intro-II + meshing), L3 (demos-I)

Week 2:

Seminar session S1 (introductory projects)

Lab sessions Lab1 (CAD-I), Lab2 (meshing)

Deliverables: Seminar1 slide presentation and state-of-the-art project document.

Week 3:

Lab session Lab3 (Ansys)

Lecture session L4 (demos-II external guest)

Lecture session L5 (lumped models)

Lab session Lab4 (Ansys)

Brief project update via online meeting

Week 4:

Lecture session L6 (FD+FEM, CFD)

Lab session Lab5 (Visualization with Paraview)

Seminar session S2 (Materials and Methods)

Week 5:

Lecture session L7 (FEM-II + CFD)

Brief project update via online meeting

Deliverables: Lab reports

Week 6:

Lecture session L8 (V&V)

Seminar session S3 (Results presentation)

Week 7:

Brief project update via online meeting

Week 8:

Seminar session S4 (final results presentation)

Deliverables: Slide presentation and final results submission for S4

Week 9:

Brief project update via online group meetings

Deliverable: Practice presentation recording to gather feedback

Week 10:

Final project presentation

Deliverables: Final slide presentation and submission of final journal article

Sustainable Development Goals

3 - Good Health and Well-being

Evaluation and grading system

The assessment of the MOS subject is designed assuming continuous learning and work from the students and feedback from teachers during the whole trimester, especially in labs

sessions which represent a higher than usual weight in the total assessment. The assessment of the subject, how grades will be computed, minimum requirements and which parts can be retaken (at July call) are summarized in Table 2.

Table 2: Assessment of MOS subject.

	ELEMENTS	WEIGHT	CAN BE RETAKEN
Theory (20%)	• Oral exam • Minimum grade ≥ 5	20%	Yes
Seminars (20%)	• Report on seminars	20%	Yes
Modelling project (60%)	• 10-15 minutes presentation of modelling project in week 10 • 0.5 additional point to best modelling project chosen by students • Minimum grade ≥ 5	35%	No
	• Final report (paper) • 0.5 additional point to best report chosen by teachers • Minimum grade ≥ 5	25%	Yes

Theoretical concepts seen in lectures will be evaluated at the end of the trimester during the exam period in the form of an individual oral exam, which represents 20% of the final grade. Students will need a minimum mark of 5.0 to pass the subject. If failed, this oral exam could be re-taken during the July exam period. Finally, a report summarising the results obtained in the seminars will need to be delivered (20% of final grade).

The modelling project is the main contributor to the final grades of the MOS subject, accounting for 60% of it, illustrating the relevance of practical and teamwork in this subject. The modelling project grade will be obtained from the evaluation of the final presentation (35%; minimum mark of 5.0) and the final report (scientific paper, 25%; minimum mark of 5.0). Some criteria that will be considered for the evaluation of the scientific papers are: ability to assimilate concepts on the different steps in the pipeline; ability to be familiar with open-source software and coding tools for model implementation; ability for bibliographic searches; ability on designing experiments; ability to explain with scientific rigour and criticism their own work and properly relate to the state of the art; ability to foresee advances and new applications of the existing models.

Additionally, there will be an extra 0.5 points (within the 60% of the final grades) for the best presentation (voted by all teams during the final session) and an extra 0.5 points (within the 60% of the final grades) for the best scientific paper (voted by teachers).

During the course, the use of artificial intelligence tools is allowed, as long as they help achieve higher quality results, always encouraging student creativity and the integration of knowledge acquired in the modeling course to find the most optimal solutions to real-world problems. Very important: copying and plagiarism will not be tolerated under any circumstances. Any suspicion will result in an immediate report to the ESUP Management Committee, the initiation of an institutional investigation, and consequently, disciplinary sanctions.