Academic Year	2023/2024	**Semester**	1
Course Coordinator	Zhong Liang		
Course Code	BG3112		
Course Title	Cardiovascular Engineering		
Pre-requisites	CB1117		
No of AUs	3		
Contact Hours	26hrs Lecture; 12hrs Tutorial		
Proposal Date	29 March 2023		

Course Aims

This course aims to support you to learn and understand the fundamentals in fluid mechanics and be able to apply this knowledge to solve problems in cardiovascular engineering. You would also learn and study the anatomy of the human cardiovascular system, understand blood rheology and phenomenon in blood circulation, utilize basic steady and unsteady flow models to describe flow mechanics in the cardiovascular system, and learn basic concepts in heart dynamics.

Intended Learning Outcomes (ILO)

Upon the successful completion of this course, you shall be able to:

1. Define the basic properties of fluids, the conversation laws, and fundamental concepts in fluid dynamics,
2. Apply fundamental flow equations and physical relations to solve basic flow problems in hydrostatics flow.
3. Illustrate the interior and exterior parts of the human heart, path of the blood through the cardiac circuits, cardiac conduction system, electrocardiogram, cardiac output
4. Formulate Newton's laws, normal forces, tension, the angle dependence, the general concept of friction, elasticity, stress and strain, Hooke's law, Young's modulus, shear modulus, bulk modulus, biomechanics of blood vessels
5. Interpret viscosity, viscosity of blood, Newtonian and non-Newtonian fluids, flow in pipe Reynolds numbers, turbulent and unsteady flow, understand flow in constrictions and curved pipes, dynamic viscosity, kinenamtic viscosity and apparent viscosity in cardiovascular system

Course Content

Continuum fluids and mechanics
Viscosity and viscous stresses
Benoulli's equation
Momentum balance
Viscosity
Biomechanics
Anatomy and physiology of the cardiovascular system
Cardiovascular mechanics

Arterial stiffness and arteriosclerosis
Wave propagation in arteries
Viscosity of blood and flow past bodies
Blood flow in veins
Flow in the microcirculation
Blood flow in the lung

Assessment (includes both continuous and summative assessment)

Component	Course LO Tested	Related Programme LO or Graduate Attributes	Weighting	Team/ Individual	Assess-ment rubrics
1. Final Examination (60%) (2hrs, closed book)	1-5	(a), (b), (c), (d)	60 %	Individual	See appendix 1
2. Tutorial Assessment (40%) a. Quiz 1 (20%)	1-5	(a), (b), (c), (d)	20 %	Individual	See appendix 1
b. Quiz 2 (20%)	1-5	(a), (b), (c), (d)	20%	Individual	See appendix 1
Total			100 %		

Mapping of Course ILOs to EAB Graduate Attributes

Course Intended Learning Outcomes	Cat	EAB's 12 Graduate Attributes*											
		(a	(b	(c	(d	(e)	(f)	(g	(h	(i)	(j)	(k	(l)
	Core	●	●	●	●		o	o					
1. Define the basic properties of fluids, the conversation laws, and fundamental concepts in fluid dynamics		(a), (b), (c), (d)											
2. Apply fundamental flow equations and physical relations to solve basic flow problems in hydrostatics flow.		(a), (b), (c), (d)											
3. Understand the interior and exterior parts of the human heart, path of the blood through the cardiac circuits, cardiac conduction system, electrocardiogram, cardiac		(a), (b), (c), (d)											

output	
4. Understand Newton's laws, normal forces, tension, the angle dependence, the general concept of friction, elasticity, stress and strain, Hooke's law, Young's modulus, shear modulus, bulk modulus, biomechanics of blood vessels	(a), (b), (c), (d)
5. Understand viscosity, viscosity of blood, Newtonian and non-Newtonian fluids, flow in pipe Reynolds numbers, turbulent and unsteady flow, understand flow in constrictions and curved pipes, dynamic viscosity, kinenamtic viscosity and apparent viscosity in cardiovascular system	(a), (b), (c), (d)

Legend:

- ● Fully consistent (contributes to more than 75% of Intended Learning Outcomes)
- ◐ Partially consistent (contributes to about 50% of Intended Learning Outcomes)
- o Weakly consistent (contributes to about 25% of Intended Learning Outcomes)
- Blank Not related to Student Learning Outcomes

Formative feedback

Examination results;
Marker's report on overall examination performance will be uploaded to NTUlearn;
Quiz answers will be discussed in class

Learning and Teaching approach

Approach	**How does this approach support students in achieving the learning outcomes?**
Lecture	Demonstrate how to think through and carry out a procedure (e.g., working through a problem). Depending on the lecturer incomplete handouts or no handouts at all will be used to encourage you to participate in class. Guest Lectures will help give more real-world context for this course.
Tutorial	TBL classroom discussion sessions on tutorial questions and related topics

Reading and References

1. Transport Phenomena in Biological Systems by George Truskey, Fan Yuan and David F. Katz (2010)
2. Introduction to Fluid Mechanics by Robert W. Fox, Phillip J. Pritchard, Alan T. MacDonald, 7th edition (2010)
3. Biofluid Mechanics: the human circulation by Krishnan B. Chandran, Ajit P. Yoganathan and Stanely E. Rittgers (2007)
4. Analysis of Transport Phenomena by William Dean (1998)
5. Applied Fluid Mechanics by Tasos C Papanastasiou (1994)
6. Computational and mathematical methods in cardiovascular physiology by Liang Zhong (2019)

Course Policies and Student Responsibilities

General: Students are expected to complete all online activities and take all scheduled assignments and tests by due dates. Students are expected to take responsibility to follow up with course notes, assignments and course related announcements. Students are expected to participate in all tutorial discussions and activities.

Continuous assessments: Students are required to attend all continuous assessments.
Absenteeism: Continuous assessments make up a significant portion of students' course grade. Absence from continuous assessments without officially approved leave will result in no marks and affect students' overall course grade.

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. Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.

Course Instructors

Instructor	Office Location	Phone	Email
Liang Zhong	N1.2-B2-10	67042237	cs-liang.zhong@ntu.edu.sg

Planned Weekly Schedule

Week	Topic	Course LO	Readings/ Activities
1	Introduction of fluid mechanics	1	Lecture, textbook
2	Mass, energy and momentum balance	2	Lecture, textbook
3	Anatomy and physiology of the cardiovascular system	3	Lecture, textbook
4	Cardiovascular mechanics	4	Lecture, textbook
5	Viscosity and turbulent flow	5	Lecture, textbook
6	Arterial stiffness and arteriosclerosis	4	Lecture, textbook
6	Quiz 1	-	-
7	Blood flow in arteries	1,3,5	Lecture, textbook
8	Viscosity of blood and flow past bodies	5	Lecture, textbook
9	Blood flow in veins	1,3,5	Lecture, textbook
10	Flow in the microcirculation (I)	1,3,5	Lecture, textbook
11	Flow in the microcirculation (II)	1,3,5	Lecture, textbook
12	Blood flow in the lung (I)	1,3,5	Lecture, textbook
12	Quiz 2	-	-
13	Blood flow in the lung (II)	1,3,5	Lecture, textbook

Appendix 1: Assessment Criteria

Criteria	Unsatisfactory <40%	Borderline 40% to 49%	Satisfactory 50% to 69%	Very Good 70% to 89%	Exemplary >90%
Define the basic properties of fluids, the conversation laws, and fundamental concepts in fluid dynamics	Cannot define or evaluate concepts and properties of fluids	Can define and evaluate concepts and properties of fluids	Can define, explain, and evaluate concepts and properties of fluids	Can define, explain, analyse, and evaluate concepts and properties of fluids	Can define, explain, analyse, synthesize, and evaluate concepts and properties of fluids
Apply fundamental flow equations and physical relations to solve basic flow problems in hydrostatics and pipe flow.	Cannot define or evaluate fundamental flow equations	Can define and evaluate fundamental flow equations	Can define, explain, and evaluate fundamental flow equations	Can define, explain, analyse, and evaluate fundamental flow equations	Can define, explain, analyse, synthesize, and evaluate fundamental flow equations
Illustrate cardiovascular physiology relevant to fluid mechanics in human circulation.	Cannot define anatomical or physiological components related to human circulation	Can define anatomical or physiological components related to human circulation	Can define and explain anatomical or physiological components related to human circulation	Can define, explain, and discuss anatomical or physiological components related to human circulation	Can define, explain, discuss, and connect concepts in fluids to anatomical or physiological components related to human circulation
Define the fluid properties and behaviours in blood rheology, and perform basic viscometry calculations to determine fluid properties.	Cannot define or evaluate concepts and properties of fluids	Can define and evaluate concepts and properties of fluids	Can define, explain, and evaluate concepts and properties of fluids	Can define, explain, analyse, and evaluate concepts and properties of fluids	Can define, explain, analyse, synthesize, and evaluate concepts and properties of fluids
Apply Bernoulli equation to solve flow problems in hemodynamics.	Cannot define or evaluate Bernoulli equation in context of hemodynamics	Can define and evaluate Bernoulli equation in context of hemodynamics	Can define, explain, and evaluate Bernoulli equation in context of hemodynamics	Can define, explain, analyse, and evaluate Bernoulli equation in context of hemodynamics	Can define, explain, analyse, synthesize, and evaluate Bernoulli equation in context of hemodynamics

Explain the concepts of steady and unsteady flow models and apply them in different cardiovascular flow problems.	Cannot define or evaluate unsteady or steady flow in CV systems	Can define and evaluate unsteady or steady flow in CV systems	Can define, explain, and evaluate unsteady or steady flow in CV systems	Can define, explain, analyse, and evaluate unsteady or steady flow in CV systems	Can define, explain, analyse, synthesize, and evaluate unsteady or steady flow in CV systems
Apply the knowledge of basic heart mechanics to perform basic hemodynamic assessment of heart valves	Cannot define anatomical or physiological components related to human circulation	Can define anatomical or physiological components related to human circulation	Can define and explain anatomical or physiological components related to human circulation	Can define, explain, and discuss anatomical or physiological components related to human circulation	Can define, explain, discuss, and connect concepts in fluids to anatomical or physiological components related to human circulation

Appendix 2: The EAB (Engineering Accreditation Board) Accreditation SLOs (Student Learning Outcomes)

a) **Engineering knowledge:** Apply the knowledge of mathematics, natural science, engineering fundamentals, and an engineering specialisation to the solution of complex engineering problems
b) **Problem Analysis:** Identify, formulate, research literature, and analyse complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
c) **Design/development of Solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations.
d) **Investigation:** Conduct investigations of complex problems using research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
e) **Modern Tool Usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modelling to complex engineering activities with an understanding of the limitations
f) **The engineer and Society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal, and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
g) **Environment and Sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for the sustainable development.
h) **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
i) **Individual and Team Work:** Function effectively as an individual, and as a member or leader in diverse teams and in multidisciplinary settings.
j) **Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
k) **Project Management and Finance:** Demonstrate knowledge and understanding of the engineering and management principles and economic decision-making, and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
l) **Life-long Learning:** Recognise the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change