FitzEd
EDUCATIONAL PROGRAMMES
FITZWILLIAM COLLEGE, CAMBRIDGE

FitzEd Summer School 2025 - Programme 1

Course brochure

Enjoy browsing the detailed description of all of courses that we are going to offer as part of the FitzEd Summer School in Programme 1 (13th-26th July, 2025). For each course you will also find a list of prerequisite knowledge and corresponding problems to test your readiness for our courses. To help you catch up on prerequisites that you may not meet yet, we recommended an optional reading list for most of the courses.

Dr Peter Bolgar
Director of Summer School Programme

Contents:

FITZWILLIAM COLLEGE
UNIVERSITY OF CAMBRIDGE

Chemistry

Dr Andrea Chlebikova
Senior Project Chemist at Isaac Physics, Department of Physics, University of Cambridge
College Teaching Associate at Sidney Sussex College
Special Supervisor at Newnham College
Course lecturer, Yusuf Hamied Department of Chemistry, University of Cambridge

Dr Peter Bolgar
Bye-Fellow at Fitzwilliam College, University of Cambridge
Director of Studies and College Lecturer at Magdalene College, University of Cambridge
Lecturer (Teaching) at University College London

13th-26th July, 2025

Andrea Chlebikova came to Cambridge as an undergraduate in October 2011, studying Natural Sciences at St Catharine's College, specialising in chemistry. She continued to pursue a PhD in atmospheric chemistry, focusing on methods of predicting rate constants based on molecular structure. Andrea has previously been part of the organising team for the Cambridge Chemistry Challenge, as well as being a UKMT volunteer in charge of marking mathematics challenges and olympiads. She became involved in undergraduate teaching at Cambridge in 2015 and has been supervising first-year chemistry to students of Natural Sciences as well as more specialised physical chemistry courses ever since. She is also involved with undergraduate admissions in multiple colleges. Andrea is in charge of designing and teaching the chemistry content on the STEM SMART programme run by the University of Cambridge, preparing students from disadvantaged backgrounds for studying STEM subjects at university.

College Profile: Dr Andrea Cheblikova | Sidney Sussex College Cambridge

Peter Bolgar is a teaching Bye-Fellow in organic and bio-organic chemistry at Fitzwilliam College. He completed his undergraduate degree in Natural Sciences at Cambridge, followed by a PhD in supramolecular chemistry at the same place. His research focused on the synthesis and characterisation of sequence polymers that are able to form sequence-selective duplexes, similar to nucleic acids. Peter now specialises in teaching chemistry at the university level, lecturing a range of courses from the first, second and third year of the undergraduate curriculum. He is involved with undergraduate admissions at Magdalene College. Peter is a member of the UK Chemistry Olympiad Committee, and he mentors students for the International Chemistry Olympiad both nationally and internationally.

College Profile: https://www.fitz.cam.ac.uk/person/dr-peter-bolgar

Module Structure and Syllabus:

This course lets participants explore advanced topics in physical and organic chemistry, each of which are fundamental to your studies of a chemistry degree. The course is built on concepts that you will be familiar with from school curriculum. We will quickly extend your knowledge in the fields of atomic and molecular orbital theory, thermodynamics, kinetics and organic reactivity to give you a significant head start in your university education. You will be able to practice your experimental skills as well through a practical class in physical chemistry. We are looking forward exploring the highlights of first year undergraduate-level Chemistry curriculum with you!

Date	**14th July Monday**	**15th July Tuesday**	**16th July Wednesday**	**17th July Thursday**	**18th July Friday**
	Physical Chemistry: Thermodynamics Dr Chlebikova	Physical Chemistry: Kinetics Dr Chlebikova	Theoretical Chemistry: Quantum Mechanics Dr Chlebikova	Supervision Day Dr Chlebikova	Organic Chemistry: Isomerism, Conjugation, Acids & Bases Dr Bolgar
Date	**19th July Saturday**	**21th July Monday**	**22nd July Tuesday**	**23rd July Wednesday**	**24th July Thursday**
	Organic Chemistry: Introduction to Organic Reaction Mechanisms Dr Bolgar	Organic Chemistry: Introduction to Reaction Types Dr Bolgar	Guided Presentation and Essay Writing Dr Chlebikova	Laboratory Day Dr Chlebikova	Final Presentations Dr Chlebikova

Thermodynamics: We will meet the second law of thermodynamics and introduce the quantities necessary for approaching the question of what controls to what extent a chemical process goes ahead: enthalpy, entropy and Gibbs free energy. Our exploration of chemical equilibria will then focus on justifying the shifts seen based on Le Chatelier's principle.

Chemical kinetics: In this session, we will look at rates of reactions, what factors they depend on and how we can model them. We will start with an exploration of single-step processes and see how complexity quickly emerges for multi-step reactions.

Quantum Chemistry: This session focuses on building an understanding of compounds and reactions on a sub-molecular-level. How do chemists think about chemical bonding and changes to it in a useful way, despite the counterintuitive concepts quantum mechanics introduces? We will also apply our new understanding to discuss spectroscopic techniques that allow chemists to study compounds and chemical reactions.

Supervision Day: Discussing your answers to a problem set in small groups (3-4 participants per group) led by the course instructor. You will be expected to solve the problems before your supervision and bring along your answers to the session for discussion. You will also have a chance to ask questions about anything that was unclear at the lectures.

Isomerism, Conjugation, Acids & Bases: You will learn about different types of isomerism and explore the topic of chirality and its relevance to everyday life. We will discuss principles influencing electron distribution in molecules and then look at factors that govern the acidity and basicity of organic compounds. Appreciation of acidity and basicity trends will help you better understand the reactivity of organic molecules, and why one reaction might be favoured over another when multiple reactions could take place.

Introduction to Organic Reaction Mechanisms: Understanding organic reaction mechanisms is a key skill to have for any undergraduate chemist. Following the introduction of simple concepts such as electrophiles and nucleophiles, you will learn the framework that experienced chemists use to describes organic reactions. This will enable you to rationalise reactions that you haven't seen before and lead to your much deeper understanding of organic chemistry.

Introduction to Reaction Types: We will introduce the concept of oxidation levels to help you classify organic reactions. This will be followed by a discussion of the most common types of organic reactions and factors that govern them.

Guided Presentation and Essay Writing: Individual work on your research projects led by the course instructor. You will work on your essay and presentation with the course instructor guiding you through your research.

Laboratory Day: This session will include a practical component where you will have to plan and carry out a chemistry experiment. You will have to interpret the data you obtain and reach conclusions on the basis of your findings.

Final presentations: You will present your research to other participants on the course and the course instructor.

List of prerequisite knowledge:

Confidence with algebraic manipulation of expressions, including logarithms
A knowledge of differentiation will be helpful but is not necessary
Familiarity with chemistry of secondary-school level (e.g. representations of molecules and chemical bonding, recognise terminology such as "enthalpy", some experience handling glassware)

Test your knowledge of the prerequisites! Can you answer the questions below?

1. Calculate the volume of 0.1 molar sulfuric acid necessary to neutralise 25.6 grams of calcium hydroxide.
2. Rearrange $k = Ae^{-\frac{E_a}{RT}}$ for T.
3. Draw a structural formula for propanoic acid and but-1-enol.

Recommended reading list (optional):

Foundations of Physical Chemistry: No. 40 (Oxford Chemistry Primers) by Charles P. Lawrence, Alison Rodger and Richard Compton
Foundations of Physical Chemistry: Worked Examples No. 68 (Oxford Chemistry Primers) by Nathan Lawrence, Jay Wadhawan and Richard Compton

Elements of Mathematical Economics

(Mathematics and Economics)

Vasileios Kotsidis
College Assistant Professor at Gonville and Caius College

13th-26th July, 2025

Vasileios Kotsidis uses tools from traditional and evolutionary game theory to analyse social interactions that (potentially) involve strategic motives. His research focuses on the scope and limitations of models based on methodological individualism in interpreting individual behaviour (human or otherwise) as it is manifested in social settings. It spans along three main directions: how individuals think, what they are motivated by, and what the researcher can infer. He obtained his PhD in Economics at the University of Nottingham. His doctorate explored some theoretical aspects of social (strategic) behaviour and investigated its empirical manifestations. He also enjoys practicing karate, studying on the philosophy of mathematics, and reading fantasy literature.

Department profile: https://www.econ.cam.ac.uk/people/cto/vk340

Module Structure and Syllabus:

This course explores some fundamental notions and results that are of special importance of economic analysis. It begins by considering elements of set theory, analysis, optimisation calculus, and statistics. It then applies them to construct a series of progressively more elaborate logical statements which form the basis of formal choice under risk. The result is a robust and analytically tractable approach to reasoning about uncertainty.

Date	**14th July Monday**	**15th July Tuesday**	**16th July Wednesday**	**17th July Thursday**	**18th July Friday**
	Elements of Mathematics I	Elements of Mathematics II	Elements of Statistics I	Supervision Day 1	Elements of Statistics II
Date	**19th July Saturday**	**21th July Monday**	**22nd July Tuesday**	**23rd July Wednesday**	**24th July Thursday**
	Rational Choice Theory I: Uncertainty	Rational Choice Theory II: Information	Guided Presentation and Essay Writing	Supervision Day 2	Final Presentations

Elements of Mathematics I and II: These lectures introduce students to fundamental concepts of mathematics that have useful applications in economics.

Elements of Statistics I and II: These lectures provide the statistical foundations necessary for the analysis of economic processes and relations.

Rational Choice Theory I and II: These lectures introduce a formal theory of choice under uncertainty and examine some applications in economic transactions. They discuss, in particular, attitudes towards risk, stochastic dominance, and the incorporation of new information into decision-making.

Supervision Day 1: Discussing your answers to a problem set in small groups (3-4 participants per group) led by the course instructor. You will be expected to solve the problems before your supervision and bring along your answers to the session for discussion. You will also have a chance to ask questions about anything that was unclear at the lectures.

Guided Presentation and Essay Writing: Individual work on your research projects led by the course instructor. You will work on your essay and presentation with the course instructor guiding you through your research.

Supervision Day 2: Small group (3-4 participants per group) sessions led by your course instructor where you will receive feedback on your essay and presentation drafts. Bring along the drafts to the supervision and develop your work following the course instructor's feedback.

Final presentations: You will present your research to other participants on the course and the course instructor.

List of prerequisite knowledge:

1. Understanding of limiting reasoning
2. Elementary trigonometry
3. Intuitive understanding of sets
4. Venn diagrams
5. Intuitive understanding of probability

Test your knowledge of the prerequisites! Can you answer the questions below?

1. What does it meant to state that some function, f, is continuous?
2. What does it mean to state that some function, f, is differentiable?
3. Consider two sets, A and B. Suppose that A is a subset of B. What are then the union and the intersection of A and B?

Biology: Microbiology and Pathogen Evolution

(Biology, Genetics, Microbiology, Bioinformatics)

Dr Marta Matuszewska
Research Associate, Department of Medicine, University of Cambridge and Wellcome Sanger Institute, Wellcome Trust Genome Campus

Guest lecturer: Dr Christopher Ruis
Research Associate, Department of Medicine, University of Cambridge and World Health Organization emerging zoonotic diseases consultant

13th-26th July, 2025

Marta Matuszewska, currently a Research Associate at the University of Cambridge, is an accomplished evolutionary microbiologist specialising in bacterial host adaptation. Holding a PhD in Veterinary Medicine, Marta's research is dedicated to understanding the host range and transmission dynamics of antibiotic-resistant pathogens, with particular focus on *Staphylococcus aureus*. In her current role, she is actively engaged in investigating the biological basis of nasal *by S. aureus* and the role of carriage in disease and evolution and spread of antibiotic resistance. Marta is employing a comprehensive approach that integrates microbiology and genetic epidemiology. Beyond her research, Marta actively contributes to education at the University by leading practical classes in mathematical biology and cell biology. Previously she has supervised undergraduate students in mathematical biology, nurturing the next generation of scientists. Marta also enjoys public science outreach, participating in events such as the Cambridge Science Festival, communicating complex scientific concepts to broad audiences.

Google Scholar: https://scholar.google.com/citations?user=hDJPDIgAAAAJ&hl=en
Cambridge Infectious Diseases Profile: https://www.infectiousdisease.cam.ac.uk/directory/marta-matuszewska
LinkedIn Profile: https://www.linkedin.com/in/marta-matuszewska-b92432131/

Module Structure and Syllabus:

This course provides an in-depth exploration of the genetic and evolutionary dynamics that drive pathogen adaptation and resistance, focusing on *Staphylococcus aureus* and other significant bacteria. Through lectures on molecular epidemiology, bacterial genomics, and phylogenetic analysis, students will gain foundational knowledge in understanding pathogen evolution. With a blend of theoretical concepts and hands-on activities, including guest lectures and group projects, participants will be equipped to analyse genetic data and explore real-world implications in public health and disease management.

Date	14th July Monday	15th July Tuesday	16th July Wednesday	17th July Thursday	18th July Friday
	Molecular Epidemiology	DNA Structure, Causes and consequences of mutations	Micro-organisms Classification	Supervision Day 1	Microbes and Disease
Date	**19th July Saturday**	**21th July Monday**	**22nd July Tuesday**	**23rd July Wednesday**	**24th July Thursday**
	Bacterial Genomics	Phylogenetics and Phylogenetic Inference	Guided Presentation and Essay Writing	Supervision Day 2 and Guest Lecture: SARS-CoV-2 Pandemic Response	Final Presentations

Molecular Epidemiology: An in-depth introduction to the methodologies and key definitions essential for studying the evolution of pathogens using genomic data. Students will learn the foundational concepts that underpin molecular epidemiology.

DNA Structure: A comprehensive exploration of cell structure, the intricacies of DNA and RNA molecules, and a deep dive into the Central Dogma of biology. This lecture lays the groundwork for understanding genetic information.

Causes and consequences of mutations: A detailed examination of mutations, including their definition, classification into types, an exploration of their consequences on genetic material, and an analysis of the diverse factors contributing to mutagenesis.

Micro-organisms Classification: A nuanced discussion on the principles governing the classification of microorganisms, emphasising both phenetic and phylogenetic relationships. Students will gain insights into the taxonomic frameworks that categorise these entities.

Supervision Day 1: Discussing your answers to a problem set in small groups (3-4 participants per group) led by the course instructor. You will be expected to solve the problems before your supervision and bring along your answers to the session for discussion. You will also have a chance to ask questions about anything that was unclear at the lectures

Microbes and Disease: An exploration of infectious diseases, covering the spectrum from foodborne and waterborne to airborne diseases. Students will gain a broad understanding of the diverse microbial agents responsible for various health challenges.

Bacterial Genomics: An introduction to the diverse sequencing techniques employed in bacterial genomics. The lecture will guide students through the process of transforming raw sequencing data into a comprehensible genome, providing essential insights into genomic analyses.

Phylogenetics and Phylogenetic Inference: A deep dive into phylogenetic principles, including real-world examples of phylogenies, discussions on phylogenetic tree rooting and topology, applications in diverse contexts, and a critical examination of potential pitfalls in phylogenetic analyses. Students will also learn the practical aspects of phylogenetic inference. This includes creating alignments, understanding distance matrices, selecting appropriate substitution models, and exploring various approaches to construct phylogenetic trees, such as Neighbour-Joining, Likelihood-based methods, and Bayesian phylogenetic inference.

Guided Presentation and Essay Writing: Individual work on your research projects led by the course instructor. You will work on your essay and presentation with the course instructor guiding you through your research.

Supervision Day 2: Small group (3-4 participants per group) sessions led by your course instructor where you will receive feedback on your essay and presentation drafts. Bring along the drafts to the supervision and develop your work following the course instructor's feedback.

Guest Lecture - SARS-CoV-2 Pandemic Response: A special guest lecture by Dr Christopher Ruis, offering unique insights into his work during the SARS-CoV-2 pandemic response. Students will gain a first-hand understanding of applying mutational spectra and phylogenetics to decipher pathogen transmission patterns.

Final presentations: You will present your research to other participants on the course and the course instructor.

List of prerequisite knowledge:

A broad familiarity with the items on the list above will greatly enhance your understanding and enjoyment of the classes and good preparation by all students will contribute significantly to the success of the course.

Test your knowledge of the prerequisites! Can you answer the questions below?

1. What is DNA, and what is its primary role in living organisms?
2. What is one common disease caused by bacteria?
3. What do we call medicines that help fight bacterial infections?

Recommended reading list (optional):

Brown, T. A. (2002). *Mutation, Repair and Recombination*. https://www.ncbi.nlm.nih.gov/books/NBK21114/

Costa dos Santos, G., Renovato-Martins, M., & de Brito, N. M. (2021). The remodel of the "central dogma": a metabolomics interaction perspective. *Metabolomics: Official Journal of the Metabolomic Society*, *17*(5). https://doi.org/10.1007/S11306-021-01800-8

Crick, F. (1970). Central Dogma of Molecular Biology. *Nature 1970 227:5258*, *227*(5258), 561–563. https://doi.org/10.1038/227561a0

Foxman, B., & Riley, L. (2001). Molecular Epidemiology: Focus on Infection. *American Journal of Epidemiology*, *153*(12), 1135–1141. https://doi.org/10.1093/AJE/153.12.1135

Hall A. What is molecular epidemiology? (Editorial). *Trop Med Int Health* 1996;1:407–8.

Lakhundi, S., & Zhang, K. (2018). Methicillin-Resistant *Staphylococcus aureus*: Molecular Characterization, Evolution, and Epidemiology. *Clinical Microbiology Reviews*, *31*(4). https://doi.org/10.1128/CMR.00020-18

MacPhee, D. G., & Ambrose, M. (1996). Spontaneous mutations in bacteria: chance or necessity? *Genetica*, *97*(1), 87–101. https://doi.org/10.1007/BF00132585

Pitt, T. L., & Barer, M. R. (2012). Classification, identification and typing of micro-organisms. *Medical Microbiology*, 24. https://doi.org/10.1016/B978-0-7020-4089-4.00018-4

Tompkins LS. Molecular epidemiology: development and application of molecular methods to solve infectious disease mysteries. In: Miller VL, Kaper JB, Portnoy DA, et al, eds. Molecular genetics of bacterial pathogenesis: a tribute to Stanley Falkow. Part 1. Retrospective look at early advances. Washington, DC: American Society for Microbiology, 1994:63–73

Philosophy of Science in Cambridge: Then and now

Dr Alex Carter
Associate Professor of Philosophy and Interdisciplinary Studies, ICE, University of Cambridge.
College Lecturer in Interdisciplinary Studies, Fitzwilliam College

13th-26th July, 2025

Alex Carter teaches Philosophy and Creativity Theory at the University of Cambridge, Institute of Continuing Education. He also oversees the Institute's undergraduate research courses. At Fitzwilliam College, Alex supervises philosophy students and provides study skills support to all college members. Alex's research interests are diverse and include Wittgenstein's later philosophy, the theology of Simone Weil and the philosophy of humour. Alex's PhD thesis explored some of the surprising aspects of Wittgenstein's views concerning freedom and fatalism. Alex is currently researching the relationship between humour and creative practice via the concept of 'serious play'.

www.ice.cam.ac.uk/about-us/staff-profiles/tutor/dr-alex-david-carter
www.fitz.cam.ac.uk/person/dr-alexander-carter
Www.ADCPhilosophy.com

Module Structure and Syllabus:

From Isaac Newton to Alan Turing, Francis Bacon to Stephen Hawking, Charles Darwin to Rosalind Franklin, James Fraser to Jane Goodall—Cambridge is renowned for its scientific breakthroughs. In this course, we explore the deeper, philosophical significance of these discoveries and ask: Is space a "stuff"? Are human beings "special"? Is mathematics certain? Can machines think? The course welcomes those new to philosophy, and invites students to apply their knowledge of other subjects in critical and creative ways.

Date	**14th July Monday**	**15th July Tuesday**	**16th July Wednesday**	**17th July Thursday**	**18th July Friday**
	Philosophical faces and places of Cambridge	Cambridge's Natural Philosophers	Cambridge Platonism	Supervision Day 1	Philosophy, Science and Divinity
Date	**19th July Saturday**	**21th July Monday**	**22nd July Tuesday**	**23rd July Wednesday**	**24th July Thursday**
	Cambridge's Analytic philosophers	Wittgenstein's Lectures on the Foundation of Mathematics	Guided Presentation and Essay Writing	Supervision Day 2	Final Presentations

Philosophical faces and places of Cambridge: We will explore a map of Cambridge to identify the key places where philosophical discoveries took place, including Fitzwilliam College itself. This will give students an overview of the course and allow students to go out and see the places we are talking about.

Cambridge's Natural Philosophers: Today, we think of Newton and Darwin as scientists. But in their own time, they were natural philosophers. We will consider the controversial and groundbreaking discoveries of these two natural philosophers; as well as the philosophical insights that inspired them.

Cambridge Platonism: In 17th Century Cambridge witnessed a resurgence of Plato's philosophy, spearheaded by Ralph Cudworth and Henry More. This session will give us the opportunity to (re)consider Plato's philosophy through the writings of these Cambridge philosophers.

Supervision Day 1: Discussing your answers to a problem set in small groups (3-4 participants per group) led by the course instructor. You will be expected to solve the problems before your supervision and bring along your answers to the session for discussion. You will also have a chance to ask questions about anything that was unclear at the lectures.

Philosophy, Science and Divinity: We will reflect on some of the themes considered in the preceding session. Historically, how do science, theology and philosophy interact, and is it still the same today?

Cambridge's Analytic Philosophers: This session introduces the 20th Century philosophies of Russell, Moore and Wittgenstein. All three philosophers sought to provide definitive answers to questions about the nature of reality.

Wittgenstein on the Foundations of Mathematics: We will look more closely at what Wittgenstein thought about mathematics through the lectures he delivered in Cambridge in the early 20th Century. These lectures may (or may not) have influenced other important figures in Cambridge, including Frank Ramsey and Alan Turing.

Guided Presentation and Essay Writing: Individual work on your research projects led by the course instructor. You will work on your essay and presentation with the course instructor guiding you through your research.

Supervision Day 2: Small group (3-4 participants per group) sessions led by your course instructor where you will receive feedback on your essay and presentation drafts. Bring along the drafts to the supervision and develop your work following the course instructor's feedback.

Final presentations: You will present your research to other participants on the course and the course instructor.

<u>List of prerequisite knowledge:</u>

No previous study of philosophy is required; although a broad familiarity with the ideas above will enhance your understanding and enjoyment of the classes and good preparation by all students will contribute significantly to the success of the course. It is also hoped that students will apply existing knowledge from other fields, e.g. physics, mathematics, law, in discussing the above topics.

Much of philosophy is about making distinctions. So, if you are unsure about your suitability, you could review the below questions. There are few (if any) perfect answers in philosophy, so it is important only that you feel confident arriving at *an* answer.

<u>Test your knowledge of the prerequisites! Can you answer the questions below?</u>

1. What is the difference between an argument and an assertion?
2. What is the difference between a paradox and a problem?
3. Can I *<u>know</u>* x if x is false?

Recommended reading list (optional):

- Beaney, M., 2017. Analytic philosophy: A very short introduction (Vol. 542). Oxford University Press. (An introductory text to Analytic philosophy)
- Monk, R. 1991, Ludwig Wittgenstein: The Duty of Genius, Penguin. (This is not a philosophy book, but a biography of Cambridge's most influential philosopher).
- Russell, B., 2001. The problems of philosophy. OUP Oxford. (This is written by another, influential, Cambridge philosopher, but it is an excellent introduction to philosophy in general)

Physics: Special Relativity and Quantum Mechanics

Joao Rodrigues
Bye Fellow of St Catharine's and Wolfson Colleges

13th-26th July, 2025

After many years working in Quantum Field Theory and Particle Physics, specifically in the parton structure of the nucleons, I changed my field of research to the climate of the polar regions. In the Polar Oceans Physics Group in Cambridge, I studied how the Arctic sea ice cover has changed in recent decades as a consequence of global warming. I examined sea ice thickness data collected by submarines and satellites and attempted to quantify the dramatic thinning of the Arctic Sea ice. At present, I teach several Physics and Mathematics courses for first-, second- and third-year students in the Natural Sciences and the Mathematical Tripos of the University of Cambridge.

College Profile: https://www.wolfson.cam.ac.uk/people/dr-joao-rodrigues

Module Structure and Syllabus:

The motion of particles at speeds close to the speed of light is described by equations that are very different from those that we apply to study the motion of the objects in our daily life, such as the planets around the Sun. Special Relativity provides the theoretical framework to study those fast moving particles. We shall study phenomena such as the time dilation, length contraction and the famous twin paradox, which have no counterpart in the classical theory.
And let us explore the Quantum World. The atomic and subatomic particles behave in a way that for us, used to the certainties of Classical Dynamics and Electromagnetism, is unambiguously strange. Quantum Mechanics suggests there is an essential randomness in quantum phenomena and the best theory we have, based on the wave function and Schrodinger equation, can only predict the probabilities of events to occur. Such peculiarities of the theory were not appealing to everyone. We shall look at how Einstein objected to the standard formulation of Quantum Mechanics and how his ideas led to new developments.

Date	**14th July Monday**	**15th July Tuesday**	**16th July Wednesday**	**17th July Thursday**	**18th July Friday**
	The Lorentz Transformation and Relativistic Kinematics	Relativistic Dynamics	Relativistic Optics and appearance of moving object	Supervision Day 1	The historical development of Quantum Mechanics
Date	**19th July Saturday**	**21st July Monday**	**22nd July Tuesday**	**23rd July Wednesday**	**24th July Thursday**
	The postulates of QM and simple applications	The EPR paradox and Bell's Inequality	Guided Presentation and Essay Writing	Supervision Day 2	Final Presentations

The Lorentz Transformation. We highlight the successes and difficulties of the pre-relativistic physics. The latter was very effective in predicting, for instance, the motion of the planets, but Einstein noticed what appeared to be an inconsistency between Newton's dynamics and Maxwell's electromagnetism. This led him to propose a new physical theory and a new transformation law for the coordinates of the same event in two different reference frames. Different observers may assign different times to the same event, a curious feature of what became known as the Lorentz transformation.

Relativistic Kinematics. The fact that time flows at different rates in different systems of reference has interesting consequences. We shall follow a fast-moving interstellar spaceship and compare the magnitudes of time intervals, distances and velocities measured by those in the ship with the corresponding measurements made by observers at rest. In this context, we shall examine in detail the well-known Twin Paradox.

Relativistic Dynamics. We introduce the notions of relativistic momentum and energy and study some examples of the conversion of mass into energy and vice-versa. We derive the famous formula $E=mc^2$ and explore its implications in some physical systems.

Relativistic Optics. The Doppler effect and the aberration of light were known phenomena in non-relativistic physics. We shall assess how Relativity modifies the classic formulas and explore some of the consequences of these changes.

Appearance of rapidly moving objects. When taking a photograph of a moving object, all rays generated at its boundaries arrive simultaneously at the camera. If the object has a non-negligible size, light rays must then leave its surface at different times. In most instances this causes a significant distortion on the appearance of objects that move at speeds close to the speed of light. However, perhaps surprisingly, some objects keep their shape in the photographs.

Supervision Day 1: Discussing your answers to a problem set in small groups (3-4 participants per group) led by the course instructor. You will be expected to solve the problems before your supervision and bring along your answers to the session for discussion. You will also have a chance to ask questions about anything that was unclear at the lectures.

The historical development of Quantum Mechanics. The first quarter of the twentieth century is often regarded as one of the most productive periods in the history of science. We shall study the ideas of Planck, de Broglie, Heisenberg, Schrodinger, and others which culminated in 1925-1926 with the formulation of the Quantum Theory.

The postulates of Quantum Mechanics and simple applications. We introduce the notion of wave function, quantised energy levels and solve Schrodinger's equation for simple systems. We discuss how the equation can be applied to more complicated systems such as the hydrogen atom and the harmonic oscillator. We derive Heisenberg's uncertainty relations and discuss their implications.

The EPR paradox and the Bohr-Einstein debate. The new ideas were not accepted without reluctance by some, among them Einstein. In 1935, together with Podolsky and Rosen, he wrote an article in which an apparent paradox suggested that the formulation of Quantum Mechanics was incomplete. We shall discuss their reasoning and the more modern version of the paradox due to Bohm.

Bell's Inequality. Almost 30 years after the EPR argument was formulated, Bell wrote what has been described as one of the most important scientific works of the 20th century, in which it was shown that Quantum Mechanics could not be completed with the so-called hidden variables. We shall have a good discussion of Bell's theorem and some of its variants, namely due to d'Espagnat.

Guided Presentation and Essay Writing: Individual work on your research projects led by the course instructor. You will work on your essay and presentation with the course instructor guiding you through your research.

Supervision Day 2: Small group (3-4 participants per group) sessions led by your course instructor where you will receive feedback on your essay and presentation drafts. Bring along the drafts to the supervision and develop your work following the course instructor's feedback.

Final presentations: You will present your research to other participants on the course and the course instructor.

List of prerequisite knowledge:

Newtonian dynamics:

- Newton's Laws
- Notions of force, mass, momentum, energy and work

Optics:

- The laws of reflection and refraction
- Notion of frequency, period, wavelength

Mathematics:

- Elementary techniques of differentiation and integration
- Techniques for solving simple first and second order differential equations (desired but not strictly necessary)

Test your knowledge of the prerequisites! Can you answer the questions below?

1. Igor is a cosmonaut in the International Space Station, orbiting the Earth at an altitude of 408 km at speed of 28000 km/h. What is his acceleration and what gravitational force does the Earth exert on him.
2. You apply a 4.9 N force to the free end of a spring, stretching it from its relaxed state by 12 mm. What is the spring constant? What force does the spring exert on you if you stretch it by 17 mm? How much work does the spring force do on your hand?
3. The wavelength of x rays produced in the Stanford Linear Accelerator is 0.067 fm; what is the frequency of these x rays?

Recommended reading list (optional):

Halliday and Resnick, *Fundamentals of Physics* (Relativity and Quantum Mechanics chapters only);
A Einstein, *The Principle of Relativity*;
R Feynman, *The Feynman Lectures on Physics*, Quantum Mechanics (Chapter 1 only).

Engineering: Sustainable Vehicles

Andrea Giusti
Bye-Fellow, Fitzwilliam College, University of Cambridge
Senior Lecturer in Thermofluids, Department of Mechanical Engineering, Imperial College London

Daniel Fredrich
Research Associate, Engineering Department, University of Cambridge

13th-26th July, 2025

Andrea is a Senior Lecturer in Thermofluids at Imperial College London, Department of Mechanical Engineering and Bye-Fellow at Fitzwilliam College, Cambridge. He studied Mechanical and Energy Engineering in Florence (Italy). He obtained a PhD in 2014 at the University of Florence, working on a project for the development of clean engines for airplanes. Following his PhD, Andrea joined the Engineering Department at the University of Cambridge as a Rolls-Royce Research Associate. He was appointed Lecturer by Imperial College in October 2018. In addition to the academic role at Imperial College, Andrea supervises undergraduate students at Fitzwilliam College. He is also Editor-in-Chief of the International Journal of Spray and Combustion Dynamics.

College Profile: https://www.fitz.cam.ac.uk/person/dr-andrea-giusti
Departmental Profile: https://www.imperial.ac.uk/people/a.giusti

Daniel is a senior researcher and entrepreneur in the field of thermofluids engineering. His research focuses on the numerical prediction of thermo-acoustic instabilities and the active control of reacting multiphase flows using external electrostatic fields and non-equilibrium plasma discharges. He holds a PhD in computational fluid dynamics from Imperial College London and an MSc in aeronautics and astronautics from TU Berlin. He is the co-founder of Pinepeak Ltd, a University of Cambridge spinout aiming to solve the problem of wildfires.

Departmental Profile: https://www.eng.cam.ac.uk/profiles/df436

Module Structure and Syllabus:

The module we propose focuses on the design of new vehicles with sustainability at the centre of all engineering choices. The student will learn the fundamentals of vehicle dynamics, aerodynamic forces, electrification and new vehicle concepts. Theoretical lectures are paired with practical sessions which will guide the student towards a conceptual design of the vehicle of the future.

Date	**14th July Monday**	**15th July Tuesday**	**16th July Wednesday**	**17th July Thursday**	**18th July Friday**
	Engineering and Innovation Dr Giusti	Sustainability and life cycle assessment Dr Giusti	Vehicle Dynamics Dr Giusti	Supervision Day 1 Dr Giusti	Aerodynamic forces Dr Fredrich
Date	**19th July Saturday**	**21th July Monday**	**22nd July Tuesday**	**23rd July Wednesday**	**24th July Thursday**
	Fuels and Emissions Dr Fredrich	Electrification of transportation Dr Fredrich	Guided Presentation and Essay Writing Dr Fredrich	Supervision Day 2 Dr Fredrich	Final Presentations Dr Giusti

Engineering and Innovation: ideal engineering system, S-shaped curve, transition to the super-system, micro-scale interactions, systematic innovation, nature-inspired innovation, examples. In-class problems: finding bio-inspired solutions for the improvement of the performance of a vehicle. Assignment: definition of an ideal vehicle and identification of barriers to innovation.

Sustainability and Life cycle assessment: climate crisis, the concept of sustainability, multi-criteria decision analysis, the lifecycle of a component/system, the various phases of the life cycle assessment. In-class problems: life cycle assessment of a car. Assignment: multi-criteria decision analysis.

Vehicle Dynamics: forces on vehicles, wheels and forces exchanged on the ground, power requirements. In-class problems: identification of engine power requirements for a given performance of the vehicle. Assignment: computation of power required for a car for different slope angles of the road.

Supervision Day 1: Discussing your answers to a problem set in small groups (3-4 participants per group) led by the course instructor. You will be expected to solve the problems before your supervision and bring along your answers to the session for discussion. You will also have a chance to ask questions about anything that was unclear at the lectures.

Aerodynamic forces: fundamentals of aerodynamic friction and drag, flow separation, streamlining, wing profiles, lift and downforce. In-class problems: reduction of drag (case study). Assignment: sketch of an aerodynamic vehicle.

Fuels and emissions: classification of fuels, emissions from engines, biofuels, hydrogen. Overview of internal combustion engines, fundamentals of thermodynamics, efficiency. In-class problems: quantification of carbon dioxide emitted by hydrocarbon combustion.

Electrification of transportation: hybrid cars, fully electric cars, fundamentals of fuel cells and batteries, energy, and power density; electrification of aircrafts. Future vehicle concepts: autonomous vehicles, urban air mobility. In-class problem: evaluate the battery volume and weight for given characteristics of a vehicle (power requirement, range).

Guided Presentation and Essay Writing: Individual work on your research projects led by the course instructor. You will work on your essay and presentation with the course instructor guiding you through your research.

Supervision Day 2: Small group (3-4 participants per group) sessions led by your course instructor where you will receive feedback on your essay and presentation drafts. Bring along the drafts to the supervision and develop your work following the course instructor's feedback.

Final presentations: You will present your research to other participants on the course and the course instructor.

List of prerequisite knowledge:
Fundamental concepts of mechanics (Newton's second law, friction force, velocity, acceleration along a straight line); the concept of energy and power. Chemical reactions (reading reactants and products; balancing the reaction).

Test your knowledge of the prerequisites! Can you answer the questions below?

1. Consider a block sliding on a table with speed U=10 m/s. The kinematic friction coefficient between the block and the table is $\mu = 0.1$. The block is pushed against the table with a normal force equal to 10 N. What is the force parallel to the table that must be applied to the block to keep it moving at constant speed? How much power is needed to move the block?
2. A ball of mass 1 kg is launched vertically from the ground with speed 20 m/s. Assuming that gravity is the only force acting on the ball, what is the maximum height reached by the ball?
3. Methane, CH_4, reacts with oxygen, O_2. Find the minimum mass of oxygen per unit mass of methane to completely convert carbon into CO_2 and hydrogen into H_2O.

Recommended reading list (optional):
Any book on physics and chemistry for high school.

Computer Science: Artificial Intelligence and Machine Learning

Dr John Fawcett
Churchill College, University of Cambridge

13th-26th July, 2025

Since completing his PhD, John Fawcett has been working in industry alongside lecturing, tutoring, supervising and directing studies in Computer Science at Cambridge. Over more than 15 years, John has seen around 500 students through to graduation. John has delivered courses in summer schools for over 10 years and is active in undergraduate admissions, including as Subject Convenor for the Computer Science undergraduate course. John served as University Senior Proctor in the 2021/22 academical year after being Praelector for 6 years at Churchill.

College Profile: https://www.chu.cam.ac.uk/fellows/dr-john-fawcett/

Module Structure and Syllabus:

Artificial intelligence (AI) and machine learning (ML) have featured in the news regularly in recent years as technology continues to transform our social and work lives. This course explores the problems that we can solve with AI and ML and takes a deep dive into how we create them, including the key maths and algorithms. It moves from narrow-focused classical AI systems to solving open-ended problems that humans cannot necessary solve. Looking beyond today's AI and ML systems, the course looks at the challenges that the technology has still to overcome, posturing you to understand the next wave of developments.

Date	**14th July Monday**	**15th July Tuesday**	**16th July Wednesday**	**17th July Thursday**	**18th July Friday**
	Classic search problems in artificial intelligence	Scaling to real world search problems	Interactive decision making	Supervision Day 1	Prolog
Date	**19th July Saturday**	**21th July Monday**	**22nd July Tuesday**	**23rd July Wednesday**	**24th July Thursday**
	Understanding Knowledge	Training a Neural Network	Guided Presentation and Essay Writing	Supervision Day 2	Final Presentations

Classic search problems in artificial intelligence: many problems have a solution; many games have an optimal strategy. But how do we find them? What data structures and algorithms can we use?

Scaling to real world search problems: redesigning our algorithms to better match the limits of modern hardware and to handle different user requirements.

Interactive decision making: how can we handle problems that change while we are implementing our solution? Dynamic, or interactive, search problems pose interesting new challenges!

Supervision Day 1: Discussing your answers to a problem set in small groups (3-4 participants per group) led by the course instructor. You will be expected to solve the problems before your supervision and bring along your answers to the session for discussion. You will also have a chance to ask questions about anything that was unclear at the lectures.

Prolog: we will learn a new programming language that can help us to implement our AI algorithms!

Understanding knowledge: each of us has an intuitive understanding of common sense and knowledge, but how can we represent that in a computer, and what format(s) make it usable?

Training a neural network: generalising our approach, can we design systems that can design themselves?

Guided Presentation and Essay Writing: Individual work on your research projects led by the course instructor. You will work on your essay and presentation with the course instructor guiding you through your research.

Supervision Day 2: Small group (3-4 participants per group) sessions led by your course instructor where you will receive feedback on your essay and presentation drafts. Bring along the drafts to the supervision and develop your work following the course instructor's feedback.

Final presentations: You will present your research to other participants on the course and the course instructor.

List of prerequisite knowledge:

No computer science knowledge is assumed but programming experience is always useful.

Test your knowledge of the prerequisites! Can you answer the questions below?

Suppose you have a function that can tell you which of two items, A and B, should come first in a sorted list.

1. What is the difference between a tree and a graph data structure?
2. Why might breadth first search not perform well on a graph?
3. Why might depth first search not perform well on a graph?

Mathematics for Natural Sciences, Option 1

Dr Stephen Sawiak
Fellow, Tutor, College Lecturer, Assistant Director of Studies in Mathematics for Natural Sciences
Fitzwilliam College, University of Cambridge

MRI Physicist, Department of Physiology, Development and Neuroscience
University of Cambridge

13th-26th July, 2025

Dr Sawiak is an experienced lecturer, supervisor and assistant director of studies responsible for organising the mathematics supervisions for students taking physical Natural Sciences, Computer Science and Chemical Engineering courses in Fitzwilliam College. He has interviewed Natural Sciences candidates for over 15 years and supervised students in mathematics for 18 years. Day to day he conducts research in magnetic resonance imaging acquisition and analysis methods with applications to neuroscience.

College Profile: https://www.fitz.cam.ac.uk/person/dr-stephen-sawiak

Module Structure and Syllabus:

This exciting and challenging mathematics course gives a rapid tour from the fundamentals of calculus (differentiation and integration) up to first-year University level with advanced applications including power series expansion of functions, Fourier series and the extension of integration into multiple dimensions and non-Cartesian coordinate systems. The pace of this course will be fast and most suitable for those with already some familiarity with the basic concepts of calculus who are keen for a preview of University level mathematics made accessible to those of a bright high school level.

Date	14th July Monday	15th July Tuesday	16th July Wednesday	17th July Thursday	18th July Friday
	Sums, series convergence	Calculus I Differentiation	Taylor Series	Supervision Day 1	Calculus II Integration
Date	**19th July Saturday**	**21th July Monday**	**22nd July Tuesday**	**23rd July Wednesday**	**24th July Thursday**
	Fourier Series	Multiple integration	Guided Presentation and Essay Writing	Supervision Day 2	Final Presentations

Series, sums and convergence: Arithmetic and geometric series, mixed series, defining an infinite sum, determining convergence, limits.

Calculus I: Differentiation. Definitions, product and chain rules, examples.

Taylor series: Finding power series from first principles, combining series and applications to approximation.

Supervision Day 1: Discussing your answers to a problem set in small groups (3-4 participants per group) led by the course instructor. You will be expected to solve the problems before your supervision and bring along your answers to the session for discussion. You will also have a chance to ask questions about anything that was unclear at the lectures.

Calculus II: Integration. Definitions, relationship to differentiation, integration by parts, harder problems.

Fourier series: Expressing functions in terms of a series of sine and cosine basis functions, applications.

Multiple integration: Integration in multiple dimensions, spherical and cylindrical coordinate systems.

Guided Presentation and Essay Writing: Individual work on your research projects led by the course instructor. You will work on your essay and presentation with the course instructor guiding you through your research.

Supervision Day 2: Small group (3-4 participants per group) sessions led by your course instructor where you will receive feedback on your essay and presentation drafts. Bring along the drafts to the supervision and develop your work following the course instructor's feedback.

Final presentations: You will present your research to other participants on the course and the course instructor.

List of prerequisite knowledge:
Basic algebra, trigonometry (functions sin, cos, tan; use of radians)

Test your knowledge of the prerequisites! Can you answer the questions below?

1. What does the gradient of a function mean?
2. If x(a+b/2)=6, what is b in terms of a and x?
3. Sketch the graphs of $\sin x$ and $\cos x$, in radians, from $-\pi < x < \pi$

Mathematics for the Natural Sciences, Option 2

Mrs Serena Povia
College Teaching Associate at St John's College
Supervisor at Magdalene and Jesus
Involved in Cambridge Admissions for the past 7 years in several colleges
STEMSMART Supervisor

13th-26th July, 2025

Mrs. Serena Povia specialises in teaching Mathematics and Physics at the University level. She has been a supervisor in physics and mathematics for the Natural Sciences course for about ten years. Current teaching commitment are the Physics and Mathematics courses for the first year and the second year. Sereba previously taught third year courses too.

College Profile: https://www.joh.cam.ac.uk/fellow-profile/410

Module Structure and Syllabus:

Date	**14th July Monday**	**15th July Tuesday**	**16th July Wednesday**	**17th July Thursday**	**18th July Friday**
	Differential Equations 1	Integration 1	Complex Numbers	Supervision Day 1	Differential Equations 2
Date	**19th July Saturday**	**21th July Monday**	**22nd July Tuesday**	**23rd July Wednesday**	**24th July Thursday**
	Introduction to multivariable calculus	Differential Equations 3	Guided Presentation and Essay Writing	Supervision Day 1	Final Presentations

Differential equations 1: Using physics we introduce the need to use differential equations with some simple examples – possibly including systems of differential equations in nuclear decay.

Integration 1: A very flexible day on integration – it serves as a recap and extension for those who have done a lot of integration and as an introduction for those who have not seen much integration yet.

Complex Numbers: We need the formalism of complex numbers to solve harder physics problems. We introduce and use the cartesian and polar forms.

Supervision Day 1: Discussing your answers to a problem set in small groups (3-4 participants per group) led by me. You will be expected to solve the problems before your supervision and bring along your answers to the session for discussion. You will also have a chance to ask questions about anything that was unclear at the lectures.

Differential equations 2: Simple harmonic oscillator physics requires a different style of solution that will use Complex Numbers.

Introduction to multivariable calculus: if we need to describe physical phenomena, we need to be able to express quantities in more than one dimension. We look at how to interpret a scalar function of two variables as a surface. We may have time to cover some examples of multivariable integration.

Differential equations 3: We cover simple examples of multivariable differential equations (for example wave equation, Laplace equation, Diffusion Equation).

Guided Presentation and Essay Writing: Individual work on your research projects (essay and presentation) led by me.

Supervision Day 2: Small group (3-4 participants per group) sessions where you will receive feedback on your essay and presentation drafts. Bring along the drafts to the supervision and develop your work following the course instructor's feedback.

Final presentations: You will present your research to other participants on the course and the course instructor.

Prerequisites: derivatives (polynomials, trigonometric, exponentials, ln), product and chain rules for derivatives, integrals (polynomials, trigonometric, exponentials, ln), integrations by substitution, at least some knowledge of complex numbers.

Note: this course will be very closely targeted at students between lower and upper sixth, those who have not seen and worked on the following pre-requisites will find the course very hard. Those who have already completed pre-university studies might find at least half of the course too easy. A question sheet will be pre-circulated to participants two weeks before the course to ensure that the prerequisites are met.

Psychology and Neuroscience, Option 1

Dr Aude Rauscent
Visiting Research Fellow, Department of Psychology
Bye-Fellow at Homerton College, Fitzwilliam College and Hughes Hall
Director of Studies for Psychological and Behavioural Sciences and Natural Sciences

Dr Alexandra Krugliak
Research Associate at MRC Cognition and Brain Sciences Unit, University of Cambridge
Supervisor, Trinity College, University of Cambridge

13th-26th July, 2025

Dr Aude Rauscent is a visiting research fellow at the Department of Psychology, University of Cambridge, and one of the Directors of Studies in Psychological and Behavioural Sciences and Natural Sciences at various colleges across the University. Aude studied at the University of Bordeaux, France, where she graduated in 2008 in Neuroscience and Neuropharmacology. During her PhD, she developed a new experimental model to investigate the plasticity of the central nervous system in the face of environmental or morphological constraints, allowing the maintenance of adapted behaviours. Aude then moved to the laboratory of Professor David Belin at the French Institute of Health and Medical Research, where she investigated the psychological, neural, and cellular mechanisms of individual vulnerability to developing compulsive disorders. Ten years ago, Aude moved to Cambridge University and continued her research on the neurological and psychological mechanisms subserving individual vulnerability to addiction in the CLIC, Cambridge Laboratory for research on Impulsive and Compulsive disorders, in the Department of Psychology.

Dr Alexandra Krugliak studied Psychology and Cognitive Neuroscience at The University of Maastricht (The Netherlands), before obtaining a PhD from the University of Birmingham (United Kingdom). Currently, Alexandra is a Research Associate at the MRC Cognition and Brain Sciences Unit at the University of Cambridge. Her main research interest is how the human brain represents the world around us based on perception, memory and learning, and how these processes change during healthy and pathological ageing. She combines neuro-imaging techniques such as Electroencephalography (EEG), Magnetoencephalography (MEG), and functional Magnetic Resonance Imaging (fMRI) with cutting-edge computational approaches to study neural representations of visual and auditory perception both in healthy participants and in patients with Alzheimer's disease.

https://neuroscience.cam.ac.uk/member/ak2063/

Module Structure and Syllabus:

Date	14th July Monday	15th July Tuesday	16th July Wednesday	17th July Thursday	18th July Friday
	Introduction to the fundamentals of psychology and neuroscience Dr Rauscent	The modular and integrative functional architecture of the brain Dr Rauscent	Towards an understanding of the individual vulnerability to develop psychiatric disorders Dr Rauscent	Supervision Day 1 Dr Rauscent	Cognitive Psychology Dr Krugliak
Date	**19th July Saturday**	**21st July Monday**	**22nd July Tuesday**	**23rd July Wednesday**	**24th July Thursday**
	Cognitive Neuroscience Dr Krugliak	Visual Perception Dr Krugliak	Guided Presentation and Essay Writing Dr Rauscent	Supervision Day 2 Dr Rauscent	Final Presentations Dr Rauscent

Introduction to the Fundamentals of Psychology and Neuroscience: The first lecture introduces the fundamental notions of psychology and neuroscience and provides an overview of various methods that can be deployed in psychology and behavioural science research.

The modular and integrative functional architecture of the brain: In this lecture, the students will discover some of the fundamentals of the brain's functional anatomy. They will then become acquainted with the principal neurotransmitters of the central nervous system and what happens if they malfunction.

Towards an understanding of the individual vulnerability to develop psychiatric disorders: In this lecture, the students will be introduced to the principle of individual vulnerability to develop psychiatric disorders and the methods used to study the underlying psychological and neurobiological mechanisms.

Supervision day 1: The course instructor will lead discussions around a practical problem set in small groups (3-4 participants per group). Students will be expected to have thought about the problem before the supervision and bring hypotheses and answers to the session for discussion. During this very interactive session, students will also have a chance to ask questions about anything unclear in the lectures.

Cognitive Psychology: This interactive lecture will introduce the students to theoretical frameworks that contributed to our understanding of how humans think and process information.

Cognitive Neuroscience: In this lecture, the students will learn about methods to study the human mind with neuro-imaging methods and computational approaches. This lecture will cover traditional methods as well as current trends in Cognitive Neuroscience.

Visual Perception: In this lecture, the students will discover how visual information is perceived and processed in the brain. They will learn about the organisation of the visual systems in humans and animals, visual illusions, and the effects of lesions on visual experience.

Guided Presentation and Essay Writing: Guided, individual work on your research projects led by the course instructor. Students will learn how to read a scientific paper and be taught essay writing skills. Students will work on their essays and presentations with the course instructor in the classroom, who will be available to give instant advice.

Supervision Day 2: The course instructor will lead small group sessions (3-4 participants per group) where the students receive feedback on their essay and presentation drafts. Students should bring their essay/presentation drafts to the supervision and develop their work following the instructor's feedback.

Final presentations: The students will present their research to other participants in the course and the course instructor.

List of prerequisite knowledge:

There is no prerequisite knowledge for this course. Strong analytical skills and a keen interest in Psychological and Behavioural Sciences will be particularly helpful. The course will suit students interested in Cognitive, Neuroimaging,-Neuropsychopharmacology, and Neurobiology.

Test your knowledge of the prerequisites! Can you answer the questions below?

1. One brain area, one cognitive function? Comment.
2. How do the structures in the brain communicate?
3. Can you imagine tests to assess cognitive functions?

Recommended reading list (optional):

Principles of Neural Science - Kandel
Atkinson & Hilgard's Introduction to Psychology

Future-Focused Robotics: Bridging Mechanical and Electrical Systems

Dr Rachel Thorley
Fellow in Engineering, Churchill College

13th-26th July, 2025

Rachel read Engineering at Newnham College before completing a PhD in Geoengineering for Carbon Sequestration at the University of Sheffield. She is a Fellow in Engineering at Churchill College, where she supervises undergraduate engineers in Mechanics, as well as teaching Structures, Design, and Engineering Communication. Rachel has supervised a range of industrial placements focused on developing control systems for environmental monitoring, off-grid eco homes, and low-cost wind turbines for sustainable energy. Prior to joining Churchill, she lectured in Engineering at the University of Sheffield, specializing in the practical aspects of both Electrical and Mechanical Engineering. Her research interests lie in innovation and sustainability, translating interdisciplinary concepts into real-world solutions. She is also an active member of a local makerspace, bringing expertise in rapid prototyping and digital manufacturing.

College profile: [Dr Rachel Thorley - Churchill College]

Module Structure and Syllabus:

Robotics is rapidly transforming industries—from healthcare and manufacturing to transportation and entertainment—making now the perfect time to build the knowledge and hands-on experience this field demands. This module provides a comprehensive introduction to the electrical, mechanical, and control aspects of robotics, focusing on the design and prototyping of robotic systems. You will learn how to integrate electronics, mechanical structures, and control algorithms, exploring what is involved in the construction and use of robots from a multidisciplinary perspective.

Through a blend of lectures, hands-on lab sessions, and group design projects, you will discover how to select and assemble hardware components, program control systems, and refine prototypes based on performance testing. By the end of the module, you will be able to design, build, and troubleshoot simple robotic devices, laying a solid foundation for further engineering study and real-world applications. In addition, the module incorporates an essential thread on communication skills. You will gain experience in clearly and accurately presenting ideas in written, verbal, and graphical forms, ensuring you can engage effectively with diverse audiences—an invaluable skill in both academic and professional engineering environments.

Date	**14th July Monday**	**15th July Tuesday**	**16th July Wednesday**	**17th July Thursday**	**18th July Friday**
	Applications of robotics	Mechanical Engineering	Applied Mechanical Design	Supervision Day 1: Mechanics problems	Electrical Engineering: Circuits
Date	**19th July Saturday**	**21st July Monday**	**22nd July Tuesday**	**23rd July Wednesday**	**24th July Thursday**
	Electrical Engineering: Sensors	Electrical Engineering: Microcontrollers & Integration	Guided Presentation and Essay Writing	Makerspace Visit, Rapid Prototyping & Guest Lecture	Final Presentations

Applications of robotics:
This session explores the diverse ways robotics is reshaping industries worldwide—from healthcare robots assisting surgeons, to autonomous vehicles improving transport safety, to automated drones optimizing agricultural production. Alongside these opportunities, we discuss the ethical considerations that accompany large-scale robot deployment, including workforce displacement, data privacy, and ensuring equitable access to technology. By examining both the practical applications and moral implications, students gain a holistic understanding of how robotics can drive innovation while recognising the responsibilities that come with it.

Mechanical Engineering: This session covers the core theories and broad scope of mechanical engineering, focusing on how fundamental principles—such as statics, dynamics, and materials science—underpin the design and analysis of machines. Students will learn to evaluate forces, stresses, and motion in both traditional mechanical systems and emerging robotic applications.

Applied Mechanical Design: Building on the mechanical foundations introduced earlier, this session focuses on converting theory into practical solutions for robotic systems. Students will explore how to select and combine gears, bearings, and structural components, as well as plan chassis layouts and motor configurations. By working on small-scale prototypes, they gain hands-on experience in applying mechanical engineering principles to real-world robotics challenges.

Supervision Day 1, Mechanics Problems: Discussing the students' answers to a problem set in small groups (3-4 participants per group) led by the course instructor. Students will be expected to solve the problems before their supervision and bring along their answers to the session for discussion. Students will also have a chance to ask questions about anything that was unclear to them during the lectures.

Electrical Engineering: Circuits: This session introduces the fundamentals of electrical engineering through the lens of robotics. Students will learn basic circuit theory—covering voltage, current, and resistance—and explore key electronic components such as resistors, capacitors, LEDs, and transistors. They'll gain hands-on experience using breadboards to build and test simple circuits, laying the foundation for more complex systems.

Electrical Engineering: Sensors
Sensors are a critical component in robotics, enabling robots to perceive and respond to their environment. In this session, students will explore a variety of sensor types—infrared, ultrasonic, optical—and examine their uses, limitations, and the science behind how they work. To connect sensing to real-world action, the session also introduces fundamental control theory. Students will explore the difference between open-loop and closed-loop systems, and how feedback can be used to improve a robot's performance. They'll also gain a basic understanding of how control systems help connect sensor input to responsive, intelligent movement.

Electrical Engineering: Microcontrollers & Integration: This session brings together key learning from the mechanical and electrical parts of the course. Students will use Arduino microcontrollers to program sensor inputs and control actuators, applying their knowledge of circuits, components, and mechanical systems. Through hands-on prototyping, they will begin assembling and testing a simple robot, laying the groundwork for a responsive, integrated system.

Guided Presentation and Essay Writing: This session supports students in preparing their essays and presentations, with guidance from the course instructor. Alongside developing their written and visual materials, students will have dedicated time for final assembly, testing, and debugging of their robotic builds. This hands-on troubleshooting allows them to refine both the performance of their projects and the clarity of their communication. By resolving any last-minute issues and polishing their work, students will be well-prepared and more confident going into the final presentations.

Makerspace Visit, Rapid Prototyping & Guest Lecture: This session combines a visit to a local makerspace and a guest lecture from Dr David Hardman, the Henslow Junior Research Fellow in robotics. At the makerspace, students will explore rapid prototyping tools such as 3D printing and laser cutting, and gain hands-on experience designing and fabricating simple components. They'll learn how these technologies accelerate the design process and support innovation in robotics and engineering. The session also includes a guest lecture on cutting-edge robotics research, with time for Q&A on current challenges and future career paths in the field.

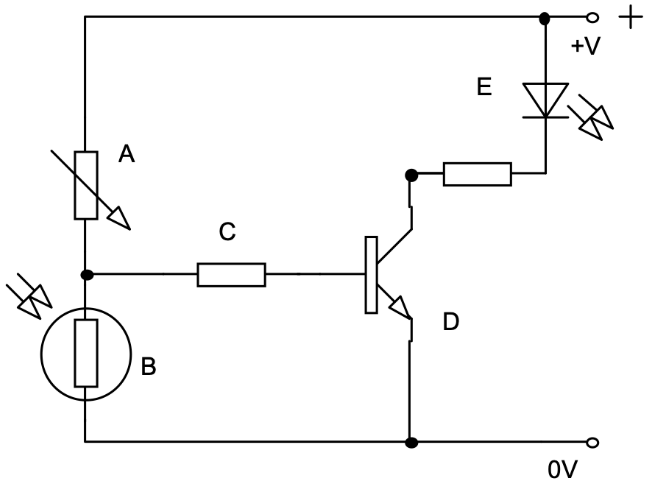
Final presentations: Students will present their research to other participants on the course and the course instructor.

List of prerequisite knowledge:

The emphasis during the course will be on the physical understanding of the principles involved. Only elementary mathematical methods will be used. The key is the engineering and not the mathematics behind it. As such, I expect students to have a basic awareness of circuits and their components, alongside a basic understanding of mechanics (see below).

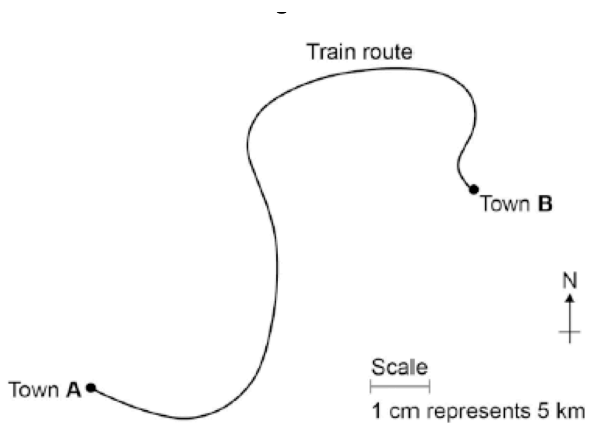
Test your knowledge of the prerequisites! Can you answer the questions below?

1. Name the components (A, B, C, D and E) in the circuit below:



2. A train travels from town A to town B ,as shown in the scale diagram below.

   a) The distance the train travels between A and B is not the same as the displacement of the train. What is the difference between distance and displacement?
   b) Use the figure below to determine the displacement of the train in travelling from A to B.
   c) There are places on the journey where the train accelerates without changing speed. Explain how this can happen.



d) The Figure below shows how the velocity of the train changes with time as the train travels along a straight section of the journey. Estimate the distance travelled by the train along the section of the journey shown.