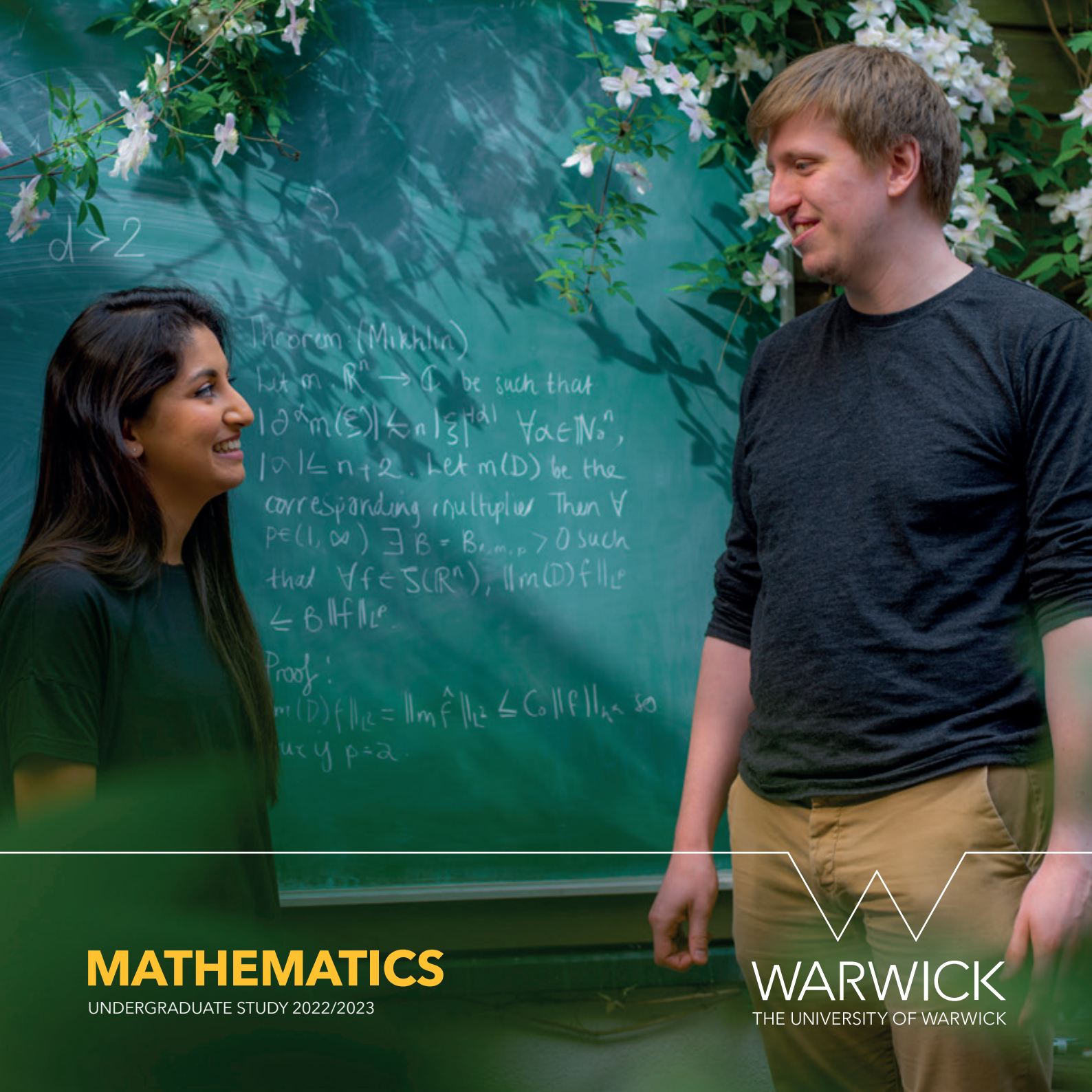



# MATHEMATICS

UNDERGRADUATE STUDY 2022/2023

WARWICK

THE UNIVERSITY OF WARWICK

**91%**

OF OUR STUDENTS SAID THAT OUR DEGREE IS INTELLECTUALLY STIMULATING IN THE

**NATIONAL STUDENT SURVEY 2020**

ONE OF ONLY FOUR UK MATHEMATICS DEPARTMENTS IN THE

**WORLD TOP 21**

*QS World Rankings 2021

IN THE 2014 RESEARCH EXCELLENCE FRAMEWORK, MORE THAN

**90%**

OF OUR RESEARCH WAS RATED AS

**'WORLD LEADING' OR 'INTERNATIONALLY EXCELLENT'**

WARWICK MATHEMATICS AND STATISTICS IS THE RECIPIENT OF THE

**QUEEN'S ANNIVERSARY PRIZE**

FOR HIGHER AND FURTHER EDUCATION

Awarded in 2015

**92%**

OF OUR 2018 UNDERGRADUATES WERE IN HIGH-SKILLED EMPLOYMENT

15 MONTHS AFTER GRADUATION*

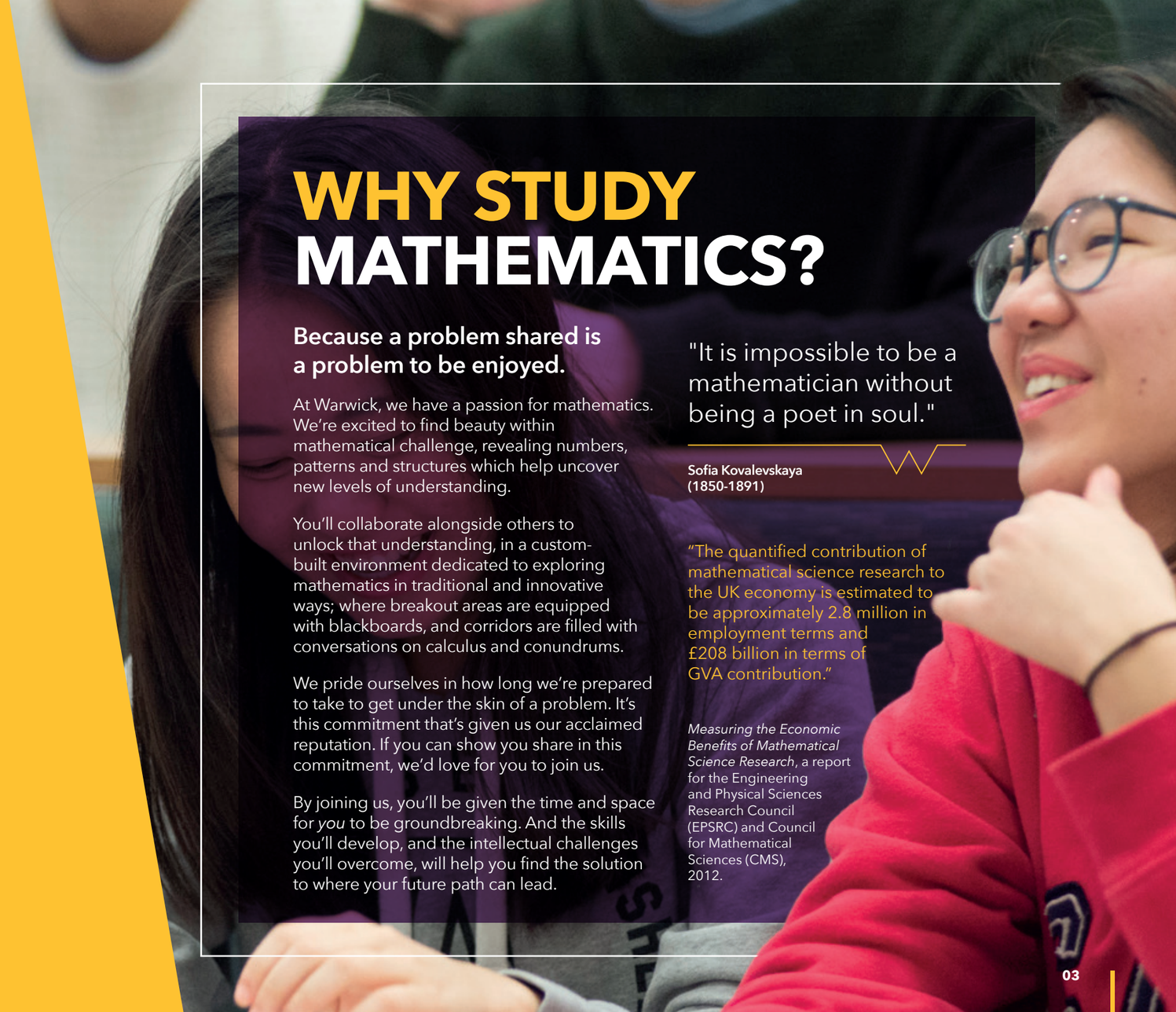
**£30,000**

IS THE AVERAGE SALARY ACHIEVED BY OUR STUDENTS

15 MONTHS AFTER GRADUATION*

* DERIVED FROM THE HESA GRADUATE OUTCOMES SURVEY FOR 2017/18, CARRIED OUT APPROXIMATELY 15 MONTHS AFTER SUCCESSFUL COMPLETION.





# WHY STUDY MATHEMATICS?

## Because a problem shared is a problem to be enjoyed.

At Warwick, we have a passion for mathematics. We're excited to find beauty within mathematical challenge, revealing numbers, patterns and structures which help uncover new levels of understanding.

You'll collaborate alongside others to unlock that understanding, in a custom-built environment dedicated to exploring mathematics in traditional and innovative ways; where breakout areas are equipped with blackboards, and corridors are filled with conversations on calculus and conundrums.

We pride ourselves in how long we're prepared to take to get under the skin of a problem. It's this commitment that's given us our acclaimed reputation. If you can show you share in this commitment, we'd love for you to join us.

By joining us, you'll be given the time and space for *you* to be groundbreaking. And the skills you'll develop, and the intellectual challenges you'll overcome, will help you find the solution to where your future path can lead.

"It is impossible to be a mathematician without being a poet in soul."

**Sofia Kovalevskaya (1850-1891)**

"The quantified contribution of mathematical science research to the UK economy is estimated to be approximately 2.8 million in employment terms and £208 billion in terms of GVA contribution."

*Measuring the Economic Benefits of Mathematical Science Research*, a report for the Engineering and Physical Sciences Research Council (EPSRC) and Council for Mathematical Sciences (CMS), 2012.

# WHY MATHS AT WARWICK?

### + SPACES DESIGNED FOR MATHEMATICAL EXPLORATION

We provide an environment designed for you to immerse yourself in mathematics. You can treat Warwick as your open workspace, allowing you and your friends to engage in mathematics wherever you find yourselves.

### + INSPIRATION THROUGH COLLABORATION

From the point you arrive at Warwick, you'll find mathematical understanding through collaboration, with both staff and students.

### + A PERSONALISED EXPERIENCE

You're free to explore a range of mathematics options, to whatever level you're comfortable with.

### + TEACHING THAT'S BOTH INNOVATIVE AND TRADITIONAL

We'll take whatever approach is necessary to give you a rich learning experience. Modern mathematical teaching practices sit alongside traditional practices, all geared towards preparing you for success after graduation.

### + AN EXCEPTIONAL, PIONEERING REPUTATION

You'll be taught in a department renowned for gathering an enviable group of academic professionals, pioneers within their field in both teaching and research.

**"You have to be prepared to work hard but once you're OK with that it's the most exciting place to study Maths."**

**Adday,** Mathematics with Intercalated Year BSc student 2015-2019 and Women in Maths representative

# YOUR WAY IN...

## MAT, TMUA and STEP

We encourage (but do not require) applicants to sit one of the following admissions tests:

- **MAT -** Mathematics Admissions Test
- **TMUA -** Test of Mathematics for University Admission
- **STEP -** Sixth Term Examination Paper

Preparing for one of these tests will help you develop your problem solving skills and deepen your understanding of mathematics.

**Here are some points you should bear in mind:**

- The MAT and TMUA are in November
- STEP is in July - there are two STEP papers and we accept either of these
- See our MAT, TMUA and STEP page for helpful resources and links explaining how to register for these tests

  **warwick.ac.uk/mathsstep**

**For further information and updates** regarding our admissions processes and entry requirements please check our website: **warwick.ac.uk/mathsadmissions/offer**

## With A Levels

Applicants for 2021 entry who take MAT or TMUA in November 2020 and do well are likely to receive the following offer:

A* (Maths), A* (Further Maths), A

Applicants for 2021 entry who do not sit either of the MAT or TMUA (or do not do well in these tests) are likely to receive the following offer:

- Either A* (Maths), A* (Further Maths), A, plus grade 1 in any STEP paper
- or A* (Maths), A* (Further Maths), A*
- or A* (Maths), A* (Further Maths), A, A

**Note:**

- We don't interview but we do invite you to attend an offer holder open day to see the department, and meet staff and current students.
- General Studies and Critical Thinking do not count towards A Level requirements.

# YOUR WAY IN...

## with the International Baccalaureate

Applicants for 2021 entry who take MAT or TMUA in November 2020 and do well are likely to receive the following offer:

- 39 points overall, with 6,6,6 in Higher Level (HL) subjects, including HL Maths

Applicants for 2021 entry who do not sit either of the MAT or TMUA (or do not do well in these tests) are likely to receive the following offer:

- either 39 points overall, with 6,6,6 in HL subjects, including HL Maths, plus grade 1 in any STEP paper
- or 39 points overall, with 7 in HL Maths, and 6, 6 in two other HL subjects

## if you live outside the UK

The University of Warwick is home to a vast number of international students from over 140 countries, and the Mathematics staff are recruited world-wide and contribute to the Institute's cosmopolitan outlook. We warmly welcome applications from international students who share our passion for mathematics. Typical offers for 30 international qualifications can be found at

**warwick.ac.uk/maths/admissions/ug/otherquals**

If your qualification is not listed, or if you have any queries about entrance requirements, please contact us at **mathsadmissions@warwick.ac.uk**

Further help and advice can be found on our international study pages:

**warwick.ac.uk/study/international**

**English language:** All applicants must satisfy the University's Admissions Requirement, including a minimum level of competence in the English language.

**warwick.ac.uk/study/undergraduate/apply/language**

# MATHEMATICS DEGREES

We offer two single-subject Mathematics degrees:

**G100: Mathematics BSc**
This is a 3-year maths degree that is broad and highly flexible.

**G103: Master of Mathematics (MMath)**
This 4-year degree is a natural route for those contemplating a mathematical career in industry, business or academia.

**Course Structure for Maths BSc:**

- 1st year: 8 core modules (75% of typical workload).
- 2nd year: 5 core modules plus essay (55% of typical workload).
- 3rd year: no core, but do at least 50% maths.

The remaining modules can be chosen from mathematics or one of many subjects.

**Course Structure for MMath:**

- Same core as BSc.
- Students must do at least 75% maths each year.

**Teaching:** Most of our teaching is through lectures. These are typically 3 hours per week for each module, and delivered by a member of academic staff. Undergraduates usually take around five modules in each of Term 1 and Term 2. Term 3 is mostly for revision and examinations.

"Studying Maths at Warwick is challenging, but a nice challenge. When you put a lot of effort in and manage to work out something you've been stuck on for a while, that feeling is so rewarding."

**Helen,** MMath student 2014-2018

**Three or Four Years Maths?**

The Maths BSc and MMath have the same entrance requirements and share the same core in the 1st year. It is easy to switch from the Maths BSc to the MMath until the end of the 1st year, and from the MMath to the Maths BSc until the end of the 3rd year. If you're struggling to decide pick either and you can change your mind later.

**Taking a gap year before study?**

We welcome applicants who wish to take a 'gap year' between school and university. Just achieve your admissions offer and your place will be reserved.

**Can I study abroad or do a work placement?**

You can choose to study abroad or undertake a year-long work placement as part of either the BSc or MMath degrees. More information can be found on **page 18**.

# Modules offered in 1st year +

## 1st Year Core Maths Modules:

Foundations, Differential Equations, Introduction to Abstract Algebra, Analysis I, Analysis II, Linear Algebra, Maths by Computer, Geometry and Motion, Probability A.

## 1st Year Optional Modules

- **From Mathematics and Statistics:** Probability B, Programming for Scientists, Statistical Laboratory.
- **From Physics:** Classical Mechanics and Special Relativity, Electricity and Magnetism, Introduction to Astronomy, Introduction to Particle Physics, Quantum Phenomena.
- **From Computer Science:** Design of Information Structures, Discrete Mathematics and its Applications 2.
- **From Philosophy:** Mind and Reality, Introduction to Symbolic Logic.
- **From Economics:** Introduction to Quantitative Economics.
- **From the Warwick Business School:** Mathematical Programming I.
- **The Language Centre** at Warwick offers academic modules in Arabic, Chinese, French, German, Japanese, Russian and Spanish at a wide range of levels.

"One of my favourite things about studying Maths at Warwick is how flexible the degree has been. I was able to choose options from my very first day - and the number of options has only increased as I've gone along, allowing me to pick modules to my interests."

**Emily,** Mathematics BSc student 2015-2018

+ The list of modules varies from year to year and is subject to changes in curriculum and staff research interests. This list is accurate for the 2020–2021 academic year.



# Modules offered in 2nd year +

## 2nd Year Core Maths Modules:

Advanced Linear Algebra; Analysis III; Groups and Rings; Multivariable Calculus; Metrics, Norms and Topologies; Second Year Essay.

## 2nd Year Optional Modules

- **From Mathematics and Statistics:** Combinatorics, Geometry, Introduction to Partial Differential Equations, Combinatorial Optimization, Theory of ODEs, Introduction to Systems Biology, Introduction to Number Theory, Variational Principles, Games Decisions and Behaviour, Introduction to Mathematical Statistics, Stochastic Processes.
- **From Physics:** Hamiltonian Mechanics, Computational Physics, Quantum Mechanics and its Applications, Electromagnetic Theory and Optics, Physics of Fluids, Stars, Methods of Mathematical Physics.
- **From Computer Science:** Algorithms, Logic and Verification, Algorithmic Graph Theory.
- **From Economics:** Mathematical Economics 1A, Mathematical Economics 1B.
- **From Warwick Business School:** Foundations of Accounting, Foundations of Finance, Starting a Business, The Practice of Operational Research, Mathematical Programming II.
- **From Philosophy:** Logic II, History of Modern Philosophy.
- **Interdisciplinary Modules:** Applied Imagination, Challenges of Climate Change, Genetics: Science and Society.
- **Education Studies:** Introduction to Secondary School Teaching.
- **The Language Centre** at Warwick offers academic modules in Arabic, Chinese, French, German, Japanese, Russian and Spanish at a wide range of levels.

# Modules offered in 3rd year +

The 3rd year has no core modules.

## 3rd Year Optional Modules from Mathematics and Statistics

- **Algebra and Discrete Mathematics**
  Galois Theory, Rings and Modules, Groups and Representations, Commutative Algebra, Algebraic Number Theory, Set Theory, Combinatorics II.
- **Analysis**
  Complex Analysis, Functional Analysis I, Functional Analysis II, Manifolds, Measure Theory, Markov Processes and Percolation Theory.
- **Geometry and Topology**
  Fractal Geometry, Geometry of Curves and Surfaces, Introduction to Topology, Algebraic Topology.
- **Real-World Systems and Applied Mathematics**
  Topics in Mathematical Biology, Bifurcations Catastrophes and Symmetry, Fluid Dynamics, Numerical Analysis and PDEs, Control Theory, Variational Principles.
- **Probability and Statistics**
  Bayesian Statistics and Decision Theory, Applied Stochastic Processes, Monte Carlo Methods, Mathematical Finance, Designed Experiments, Probability Theory, Multivariate Statistics, Topics in Statistics, Medical Statistics, Topics in Data Science, Bayesian Forecasting and Intervention.
- **Other**
  Problem Solving, Essay.

+ The list of modules varies from year to year and is subject to changes in curriculum and staff research interests. This list is accurate for the 2020–2021 academic year.



# Other modules offered in 3rd year +

## 3rd Year Optional Modules from Other Subjects

- **Physics:** Statistical Physics, Weather and the Environment, Physics in Medicine, Quantum Physics of Atoms, Electrodynamics, Scientific Programming, Plasma Electrodynamics, Galaxies, Optoelectronics and Laser Physics, Cosmology, Nuclear Physics.
- **Computer Science:** Complexity of Algorithms, Computer Graphics, Compiler Design, Principles of Programming Languages, Approximation and Randomised Algorithms, Algorithmic Game Theory.
- **Engineering:** Systems Modelling and Control.
- **Warwick Business School:** Business Studies I, Operational Research for Strategic Planning, Business Studies II, Simulation, Mathematical Programming III, The Practice of Operational Research.
- **The Language Centre** at Warwick offers academic modules in Arabic, Chinese, French, German, Japanese, Russian and Spanish at a wide range of levels.

# Modules offered in 4th year +

### 4th Year Core Maths Module:

Research Project/Maths in Action Project.

### 4th Year Optional Modules from Mathematics and Statistics:

- **Algebra and Discrete Mathematics**
  Lie Groups, Graph Theory, Analytic Number Theory, Elliptic Curves.
- **Analysis**
  Fourier Analysis, Stochastic Analysis, Ergodic Theory, Advanced Real Analysis, Advanced PDEs.
- **Geometry and Topology**
  Algebraic Geometry, Differential Geometry, Geometric Group Theory, Cohomology and Poincare Duality, Algebraic Curves.
- **Real-World Systems and Applied Mathematics**
  Dynamical Systems, Applied Dynamical Systems, Population Dynamics, Atmospheric Dynamics, Topics in Complexity Science, Mathematical Acoustics, Structures of Complex Systems, Epidemiology by Example.
- **Probability and Statistics**
  Brownian Motion, Bayesian Forecasting and Intervention, Applied Stochastic Processes, Monte Carlo Methods, Multivariate Statistics.
- **Theoretical Physics**
  Relativistic Quantum Mechanics, High Performance Computing in Physics, Gauge Theories in Particle Physics, General Relativity, Quantum Mechanics Basic Principles and Probabilistic Methods, Statistical Mechanics.

+ The list of modules varies from year to year and is subject to changes in curriculum and staff research interests. This list is accurate for the 2020–2021 academic year.

I've always felt like I can go to a lecturer if I need help. The staff are always happy to answer emails and have office hours so you can speak to them in person. They encourage you to ask questions during lectures if you feel confused, or are happy for you to go to them afterwards if you don't want to speak in front of the class.

**Vicki,** MMath student
2014-2018



# SUPPORT FOR LEARNING

### Tutorials
Your Personal Tutor is a member of academic staff. Tutors will advise on module choices, discuss mathematics with you in detail, help you to overcome minor and major problems, guide you through writing your 2nd year essay, and write reference letters for you.

### Supervisions (1st & 2nd Year)
Your supervisor is a postgraduate or 4th year student. Being only a little older than you, your supervisor remembers the challenges of being a 1st and 2nd year maths undergraduate and will support you through these. The supervisor marks your homework providing feedback, and endeavours to answer your questions.

### Small Analysis Classes
These help smooth the transition between school Calculus and undergraduate Analysis. Working in small groups, and supported by a Teaching Assistant (TA) and fellow students you will gradually be encouraged to move on from the situation where the TA shows you how to solve a problem to the point where you develop your approach to problem solving.

### Support Classes
Most 2nd, 3rd and 4th year modules have support classes associated with them. These are run by postgraduates who work through examples, provide homework feedback, answer questions,and often offer an alternative point-of-view from the lecturer.

### Maths Society
There is also a very active undergraduate Mathematics Society. They organise a weekly Maths Café, a student-led peer support group which offers informal problem-solving sessions and a listening ear, and produce revision notes at exam time as well as organising other academic and social activities.

# STUDY ABROAD & WORK PLACEMENTS

Although we offer two main degrees students may then elect to follow further pathways on these degrees – typically when choosing to study abroad or undertake a year-long work experience placement. If you're interested in one of these options you can apply during your second year:

**G101: Mathematics with Intercalated Year BSc**
You will spend a year studying abroad or on a work placement typically between years 2 and 3 of your degree, adding a year to your degree duration.

**G105: Mathematics with Intercalated Year MMath**
You will spend a year studying abroad or on a work placement, typically between years 2 and 3 of your degree, adding a year to your degree duration.

**G106 Mathematics (MMath) with Study Abroad**
This option will not add a year to your degree duration but instead, you will spend the third year of your degree at one of our overseas partner universities. After your year overseas, you will return to Warwick for your final year.

If you choose to study abroad we can prepare you with the necessary language skills through the Warwick Language Centre.

While we do not offer any formal support with arranging work placements, our departmental careers advisor and the university-wide careers support services are available to students and can provide support sourcing and applying for placements to those who are interested.



# AT THE FRONTIERS OF KNOWLEDGE

Mathematics is constantly evolving. The Warwick Mathematics Institute is home to a number of world-leading research groups in pure and applied mathematics that keep our department at the forefront of research developments.

Active research areas include Algebraic Geometry, Number Theory, Probability, Geometric Analysis, Dynamical Systems, Mathematical Biology and Complexity Science.

**Research initiatives involving mathematics at Warwick include:**

- **The Warwick Mathematics Research Centre.** Founded in 1964, this was the first such centre in the UK. It runs many workshops and conferences, and hosts hundreds of visiting mathematicians every year from all over the world.
- **Mathematical Interdisciplinary Research at Warwick**, fosters mathematical research and training across 11 academic disciplines.
- **The Centre for Scientific Computing**, driving high-performance computational research.
- **The Centre for Discrete Mathematics and its Applications**, brings together researchers in graph theory, combinatorics and operational research from Mathematics, Computer Science and the Business School.
- **The Alan Turing Institute.** This is the national institute for data science, founded by the Mathematics, Statistics and Computer Science departments at Cambridge, Edinburgh, Oxford, UCL and Warwick.
- **The Zeeman Institute:** SBIDER, brings sophisticated mathematics to challenges in biological sciences. Our research spans from the theoretical to practical policy advice, and from the genome to the population. At the core of our research is a desire to better understand and predict the biological world, often with the ultimate goal of controlling disease.
- **COVID 19:** Members of the Zeeman Institute are contributing to the COVID-19 modelling response, both in the UK and abroad. Our group supports the UK response to COVID-19 through membership of the Scientific Pandemic Influenza Group on Modelling (SPI-M), an expert group advising the Scientific Advisory Group for Emergencies (SAGE). Scientific evidence supporting the UK government response to COVID-19 can be found on the SAGE website, including modelling inputs and reports from SPI-M to SAGE.

# MATHS THAT COUNTS



Kat Rock is an Associate Professor in the Mathematics Institute. A Warwick MMath graduate herself, she is a mathematical epidemiologist with a particular interest in vector-borne neglected tropical diseases.

Kat investigates and develops models for human African trypanosomiasis (HAT, or more commonly known as sleeping sickness) and leads the Bill and Melinda Gates Foundation-funded research project 'HAT Modelling and Economic Predictions for Policy'. HAT is a parasitic infection, affecting large parts of Sub-Saharan Africa, that's transmitted by tsetse flies, causing debilitating symptoms and is often fatal without treatment.

The project aims to inform decision-making strategies for the elimination of the disease. Bringing together an international, multidisciplinary team of mathematical modellers, researchers and national programmes, the group assesses local elimination strategies, provides cost-effectiveness analyses and will deliver an investment case for elimination.

Kat explains, "There are two options for disease control – you either treat current infections or focus on preventing the future spread of the disease. Prevention measures vary by disease but might include vaccination and insect control. Smallpox remains the only human disease to have been completely eradicated from the globe by our deliberate intervention. Through treatment and tsetse control it is possible to greatly reduce the prevalence of sleeping sickness to manageable levels. But to get from low cases to no cases is much, much harder. My work looks at the feasibility and value of that."

"When I started my Maths degree at Warwick I had no idea what job I might do afterwards, although my Dad was keen for me to be an actuary. Some of my friends went down that route but I found the flexibility of the course allowed me to develop my own path. I became drawn to the application of maths to solve real-world problems. Even though I only took Biology to GCSE, by taking specialist modules in the second and third years, as well as undertaking relevant projects I was able to shape my degree to nurture my growing interest in the dynamics of infectious diseases."

"I frequently employ the skills I developed on my undergraduate course even now. Modules in programming, differential equations, population dynamics and systems biology are all directly relevant to my work."

# GLIMPSES OF MATHS RESEARCH AT WARWICK

You're perhaps curious about the research-level mathematics that takes place at Warwick.

Here we present a few examples of theorems and ideas due to Warwick mathematicians. These have been chosen because their statements are accessible to A-level students, even though the methods and ideas behind some are very advanced. In perusing these, you'll notice that they're not motivated by practical applications. Some of the maths research at Warwick is aimed at solving real-world problems, but most of it is driven by a burning desire to know. You'll also notice that mathematicians in other countries are involved as collaborators, and this is typical: research is international.

These examples also give rise to further natural questions and new directions. Perhaps you might solve one of these some day?



## Three Colourings of Maps

You might have heard of the Four Colour Theorem, proved in 1977 by Appel and Hanken. A map is *n-colourable* if we can colour it using n colours so that no two adjacent regions share the same colour. The Four Colour Theorem simply says that any map is four colourable. You should be able (with a little experimentation) to draw a map that isn't 3-colourable.

A list R,S,T,U of four regions in a map is called a *cycle* of length 4 if R shares a border with S, and S shares a border with T, and T shares a border with U and U shares a border with R. You can define a cycle of length 5 in the analogous way. A famous problem in graph theory (from 1976) is known as Steinberg's conjecture. This claims that a map that doesn't have cycles of length 4 or 5 is 3-colourable. Many graph theorists have tried to prove Steinberg's conjecture.

In 2016 Steinberg's conjecture was disproved by Warwick graph theorists Daniel Kral and Michael Hebdige, working with colleagues in France and Chile. In fact they constructed a map with 123 regions that doesn't have cycles of length 4 or 5 and isn't 3-colourable.

**Open problem:** Is there a map that doesn't have cycles of length 4, 5 or 6 and isn't 3-colourable?

## Irrationality of Odd Values of the Riemann-Zeta Function

We call a number *rational* if it can be written as a ratio of two whole numbers, and otherwise we say it is *irrational*. In your first week at university you'll probably see a proof that $\sqrt{2}$ is irrational. Another famous irrational number is $\pi$. For a whole number $n \geq 2$ we let:

$$\zeta(n) = 1 + \frac{1}{2^n} + \frac{1}{3^n} + \frac{1}{4^n} + \dots$$

This is the Riemann-Zeta function, one of the most fascinating functions in mathematics, and intimately related to the distribution of primes. If $n$ is even then $\zeta(n)$ can be written in terms of $\pi$ for example:

$$\zeta(2) = \frac{\pi^2}{6}, \ \zeta(4) = \frac{\pi^4}{90}, \ \zeta(6) = \frac{\pi^6}{945}, \dots$$

These expressions can be used to show that $\zeta(n)$ is irrational for even $n$. For odd $n$, it seems that $\zeta(n)$ is unrelated to $\pi$. For a long time mathematicians have been trying to prove the irrationality of these odd values of the Riemann-Zeta function, with the only success being due to Roger Apery who showed in 1978 that $\zeta(3)$ is irrational. Warwick mathematician Keith Ball, in collaboration with Tanguy Rivoal at Grenoble, showed that there are infinitely many irrational odd values of the Riemann-Zeta function.

**Open problem:** Is $\zeta(5)$ irrational?

## Mathematical Art

Saul Schleimer is a Warwick geometric topologist. He has a particular talent for helping the public (and undergraduates) appreciate advanced ideas in geometry and topology through mathematical art and concrete models. As an example we mention here one of Saul's models, developed in collaboration with Henry Segerman at Oklahoma State University. A relatively common sight in graphic designs is of three gears in contact. However, since neighbouring gears must rotate in opposite directions, none of the gears can move. Saul and Henry had the idea of designing a model of three interlocking gears that do actually move, and even printed a functional model using a 3D printer. You might want to google their article "Triple Gear" to see the mathematics that went behind the design or watch the YouTube video showing the gears in motion.

**Open problem:** Can you design a mechanism with four interlocking gears?

## Sums of Cubes

The French mathematician Joseph Lagrange proved in 1770 that every positive whole number can be written as the sum of four squares of whole numbers.

Ever since, number theorists have been trying to prove similar theorems with squares replaced by higher powers. In the 19th century a huge experiment was carried out by hand where all numbers up to 12,000 were decomposed as sums of cubes of non-negative whole numbers. On the basis of this experiment the German mathematician Carl Jacobi suggested in 1851 that every whole number bigger than 454 is the sum of seven cubes. This is now a theorem and many mathematicians have contributed towards the proof with the first steps being taken in the 1940s by Russian mathematician Linnik. But the final breakthrough that completed the proof came in 2016 and is due to Warwick number theorist Samir Siksek; we now know indeed that every number bigger than 454 is the sum of seven cubes. Amazingly, besides ingenuity the last step did not require very advanced mathematics and the proof can be understood by a first-year undergraduate.

**Open problem:** Jacobi also thought that every number bigger than 8,042 is the sum of six cubes. Is he right?



## A Module in Focus: Galois Theory

You might have wondered if there is a formula to solve a cubic equation, similar to the familiar quadratic formula. Such a formula was discovered by Niccolo Tartaglia (1500-1557) but is usually attributed to Gerolamo Cardano (1501-1576) who was the first to publish it.

To solve $ax^3+bx^2+cx+d=0$

let $p = \dfrac{3ac-b^2}{3a^2}$ and $q = \dfrac{2b^3 - 9abc+27a^2d}{27a^3}$.

Then one of the solutions is given by

$$x = \sqrt[3]{-\frac{q}{2}+\sqrt{\frac{q^2}{4}+\frac{p^3}{27}}}+\sqrt[3]{-\frac{q}{2}-\sqrt{\frac{q^2}{4}+\frac{p^3}{27}}}$$

with the other two solutions given by similar expressions. Shortly afterwards Lodovico Ferrari (1522–1565) gave a formula for solving quartic (i.e. degree 4) equations. For the next 250 years mathematicians searched in vain for a formula for solving quintic equations. Evariste Galois (1811-1832) finally showed that there is no such formula (shortly before getting himself killed in a duel). Galois studied the symmetries of the solutions, and realised that when the degree is at least 5 the symmetries are too complicated for there to be a formula. In the third year Galois Theory module these symmetries are studied and measured using the modern language of groups and fields.

The language is so powerful that along the way many seemingly hopeless questions are resolved. For example, you probably remember how to bisect an angle using a ruler and compass. In this module it is shown by dimension counting that angles can't be trisected using a ruler and compass.

# YOUR FUTURE STARTS HERE

As a Warwick graduate with a mathematics degree, you will have excellent prospects for a wide range of careers, the most popular areas being the Financial Sector (Accountancy, Actuarial and Investment Banking), Computing and Education.

Recent graduate job titles have included: Actuary, Business Intelligence Consultant, Chief Analytics Officer, Computer Games Designer, Consultant Software Engineer, Financial Consultant and Adviser, Financial Software Developer, Investment Banking Analyst, Market Risk Manager, and Mathematics Teacher.

Firms that have employed recent Warwick graduates from Mathematics and Statistics include: Adder Technology; Merril Lynch; Brainlabs; Civil Service; Conduent; Darktrace; Deloitte; Department of Helath; eBay; Ford Motor Company; Fore Consulting; Goldman Sachs; Government Actuaries; Investec; Jane Street Capital; KPMG; Lloyds; MBDA; Metaswitch; Met Office; Softwire; Solid Solutions; Sword Apak; Ten10; Xafinity.

Our Careers Service works for you, providing skills training, careers advice and information, and will continue to support you after your graduation. See **warwick.ac.uk/careersandskills**

## Why is a Warwick Maths Degree an Excellent Career Move?

In today's workplace, the ability to adapt to change and to learn new things is as important as having a particular range of knowledge.

During a Warwick Mathematics degree you will develop many of the qualities of intellect and temperament needed to meet new challenges, including:

- Analytical skills
- Logical thought processes
- Problem-solving ability
- Investigative skills
- Communication skills
- Effective working habits



# ALUMNI EXPERIENCES

**Nilanthi Gajraj,**
Mathematics BSc 2007-2010
Now Vice President, Citi

When I started my undergraduate degree in maths at Warwick I was not entirely sure what I wanted to do afterwards and had never considered banking. In my second year I got a summer internship in corporate banking at a UK financial institution, which gave me the opportunity to explore different areas of the bank and I went on to apply for capital/debt markets graduate roles.

I now work in the loans and acquisition finance team at Citi. We raise loan financings for multi-national corporations, financial institutions and governments across Europe, the Middle East and Africa.

I enjoy the diversity of the role, working on a leveraged buyout facility in Poland is very different to a high profile acquisition finance transaction for a FTSE 100 corporate for example, and the different challenges I face, be it a difficult credit, negotiating legal documents or pitching to win business from new clients.

The flexibility in the degree at Warwick enabled me to choose some modules outside of Maths which I have since found useful in my chosen career: a Principles of Finance module gave me a basic introduction into corporate finance, and an Advanced Spanish module was particularly useful when working on a Spanish transaction.

I hope to continue to develop and gain experience in my role with the short term goal of progressing to a more senior level. Within banking in London there are few women in senior roles so I'd like to help re-balance this and inspire the next generation of women.

**Benjamin Li,**
Mathematics BSc 2011-2014
Now Associate Consultant (Investment Consulting), Aon

The Mathematics degree at Warwick is challenging but as a result it is extremely rewarding. As soon as you have understood one topic/module, the next one is never too far away. The flexibility to pursue the areas of Mathematics that you most enjoy is extremely helpful – being able to tailor your degree to what you are most interested in allows you to get the most from it.

I now model pension fund assets and liabilities, helping to advise trustees on potential investment strategies to best meet benefits payable to members.

I applied for the graduate scheme in my final year of university, and have since progressed within the company. I wanted to work in an industry where I could use some of the skills that I had developed throughout my Mathematics degree, and Investment Consulting looked like the right choice.

My main motivation is to keep learning and to keep challenging myself. Where that will take me only time will tell, but I'm looking forward to finding out.

# ALUMNI EXPERIENCES

**Matthew Marshall,**
MMath 2007 – 2011

Now Data Scientist

My first job out of university was doing fraud analytics on social networks for banks and insurance companies. The 'Programming for Scientists' module gave me the minimum amount of programming knowledge I needed for this role, and in my interview I gave a presentation based on my fourth year project.

Within this role I was always interested in the machine learning side of analytics as it involved more maths, so I moved to working at a start-up where this is core to their business. I now work on prototyping and implementing models that take into account location, device profiling and a user's behaviour (through how they handle their smart phone for example) to provide authentication.

The way the degree encouraged me to think deeply and logically about abstractions helps me to think about systems; imagining how things are going to work without knowing every detail and before they've been built.

My degree also gave me the self-belief that even if something seems as complicated as algebraic topology then if I apply myself to it then I'll crack it eventually.

**Thomas Rafferty,**
Mathematics BSc 2008-2011, Complexity Science MSc 2012-2013, Mathematics and Complexity Science PhD. 2013-2016

Now Associate in Model Risk, JP Morgan

My work involves looking at the validation of risk models, particularly those used for risk management; from setting risk limits on individual trading desks to ensuring the firm has sufficient capital so that the bank can adequately mitigate its potential exposures during severely adverse market conditions.

Prior to my undergraduate degree I was fascinated by unique applications of maths, from Differential Equations to Brownian Motion. I therefore always tried to choose modules with a more applied focus, such as Topics in Mathematical Biology, Dynamical Systems, Probability, Statistics and Stochastic Processes and their Applications. These modules gave me an in-depth and diverse understanding on how to construct and test mathematical models observable phenomena which definitely influenced my career.

After my undergraduate degree I wanted to continue studying maths but with more of a focus on "real world" applications leading to my Masters and PhD, and after these I decided to join the "real world" and see how maths is used in the financial industry.

I really enjoy that I am continually learning new features and applications of maths for modelling real world behaviour.



**Dr Rachel Player**
MMath 2009-2013

Now Postdoctoral Researcher, Information Security Group, Royal Holloway

One of the best things about the MMath course at Warwick is the opportunity to study a wide range of modules. During my first two years, I followed courses in maths and physics. I discovered that my interest was in number theory and algebra, and I was able to develop this interest by following many advanced courses in these areas. In my final year I was fortunate to work with Prof. Samir Siksek, who supervised my MMath research project in number theory. This was a real turning point: Samir was extremely enthusiastic and helpful, and I enjoyed this project so much I began to think seriously about a career in research.

After graduating from Warwick, I began studying for a PhD at Royal Holloway. My background in number theory and algebra gave me a solid foundation for my specialism, cryptography. The highlight of my PhD was an internship in the Cryptography group at Microsoft Research, Redmond, USA. I went on to a postdoctoral position at Sorbonne Université in Paris, before returning to Royal Holloway.

My current role is varied and involves conducting research, writing papers, giving talks, teaching, organising workshops, and peer-reviewing others' work. Research is a dream job for me: not only being paid to work on interesting problems, but also the opportunity to travel and discuss ideas with colleagues around the world. I regularly present my work at national and international conferences – my next trip will be to New Zealand!

### Maths Quiz

For her MMath Research Project Rachel investigated factorials that can be written as sums of three Fibonacci numbers, for example $6! = F_8 + F_{11} + F_{15}$

Rachel found all such examples, and proved that there aren't any others.

**How many can you find?**

# ALUMNI EXPERIENCES

**Emma Cooke**
Mathematics BSc 2007-2010

Now Key Stage 5 Coordinator for Maths and 16+ Assistant, Sidney Stringer Academy

I'm currently a Maths teacher with a leadership role that involves planning the A Level Maths, Further Maths and Core Maths curriculum, monitoring student progress and raising achievement. I am also in my dissertation phase of a masters in Professional Education part-time at Warwick.

In my second year at Warwick I completed the Student Associate Scheme*, which involved a term-long placement in a secondary school and a two-week teaching experience and convinced me that I wanted to go into education.

I am and always will be a mathematician at heart so it's great that in my current job, I get to spend at least 80% of every working day doing maths. But even better than that, I also spend that time spreading my love of maths to others. The school I work in is situated in a very deprived area, and many of my students have significant socio-economic barriers to their learning. Smashing these barriers and seeing students succeed against all odds is what motivates me to wake up each morning with renewed passion.

*Although this particular scheme is no longer available there are numerous other opportunities for Maths students interested in teaching. For example, our optional module 'Introduction to Secondary Teaching in Mathematics' which includes a ten-day placement in a local school, or the Warwick In Africa programme.

**Natasha Agarwal**
Mathematics BSc 2014-2017

Now MA in Vocal Performance, Royal Academy of Music in London

I am training to be a classical opera singer which seems like quite a change from Maths! However I always say that both music and maths are universal languages – they're both built on very simple foundations but have the power to communicate complex ideas and emotions no matter what language you speak.

I've been singing and performing since the age of four, and at Warwick I had so many opportunities to pursue music and performance alongside my studies. I now study a wide range of repertoires, including contemporary music which is often very complex so my maths degree certainly comes in handy for that. To support my studies I also work as a private maths tutor for school pupils which is very rewarding.

One of the best things about the mathematics degree at Warwick, apart from the world-class teaching and facilities, is the flexibility of the course. In second year, we had to do an essay on a mathematical topic of our choice, and I decided to research the relationship between maths and music. This research covered a wide range of topics such as abstract algebra, geometry and partial differential equations, and it was fascinating to see the connections to my other maths modules. I also had the opportunity to study language modules and interdisciplinary modules such as "The Science of Music", which have proved extremely useful now as I have to sing in a variety of languages and understand the mechanics of vocal production and resonance.

I think one of the key messages from my story is that everybody has their own unique path in life. My path from maths to music may seem strange or unusual, but it was the right path for me. It is okay to go to university without knowing what you want to do when you leave – in fact this can often make you more open-minded when it comes to career possibilities. It is important to work hard at your degree, but it is just as important to pursue your hobbies and interests so that you develop as a well-rounded individual. Doing a Mathematics degree at Warwick is challenging in many ways, but once you've accomplished that you will seriously feel like you can achieve anything in life!

## HOW TO APPLY

Applications are made through UCAS **ucas.com**

If you are made and accept an offer, and meet any outstanding conditions, we will confirm your place and look forward to warmly welcoming you at the start of your life here at Warwick.

For more detailed information about how we process applications please visit: **warwick.ac.uk/study/undergraduate/apply**

## OVERSEAS APPLICANTS

At Warwick, we welcome applications from across the globe, and have dedicated teams available to advise and support, as well as a global network of Agents and Representatives. For more information on applying from your country see: **warwick.ac.uk/io**

## STUDENT FEES AND FUNDING

We want to ensure that, wherever possible, financial circumstances do not become a barrier to studying at Warwick. We provide extra financial support for qualifying students from lower income families. **warwick.ac.uk/studentfunding**

## ACCOMMODATION

We believe that where you live underpins your University experience. Warwick Accommodation manages around 7000 self-catering residences on campus. At Warwick, you'll enjoy the freedom of independent living alongside your fellow students but with the security of knowing you're surrounded by people who can support you should you need it. For more information visit **warwick.ac.uk/accommodation**

## DISCOVER MORE

To find out more about the University, including opportunities to visit and engage with your department of choice, visit **warwick.ac.uk/undergraduate/visits**



warwick.ac.uk/mathematics

mathadmissions@warwick.ac.uk