

‘Beyond the Formula’: Embedding ethics and sustainability in mathematics through co-creation

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Need for Ethics and Sustainability in Mathematics

- Mathematics usually taught through **memorisation** and repetitive application of **formulae**, with limited discussion of context and consequence.
- Often **limited emphasis** on the role of mathematics in addressing **societal, ethical and sustainability challenges**.
- Existing curricula rarely highlight how mathematical tools contribute to **solving global issues**.
- Students struggle to recognise the connection between **mathematics, sustainability and ethical responsibility**.
- This reinforces the perception that mathematics is **theoretical** and **disconnected** from real-world issues.

How did we embed it in our modules?

- **Co-creation** of teaching toolkit with **2 current undergraduate students**
- Toolkit includes **visually appealing posters** showcasing the **importance of sustainability and ethics** in mathematics, examples of **real-world mathematical problems** linked to these issues and **formative practice quizzes** to assess conceptual understanding
- Implemented across **two large undergraduate applied mathematics modules** for 800 engineering students (Year 1 – sustainability, Year 2 – ethics)
- Embedded as **asynchronous, formative resources** on QMUL virtual learning platform for students to use alongside course content

The mathematical exercises provided below are designed to raise sustainability and ethical awareness and imbibe transferable skills among undergraduate students in STEM disciplines as part of an ongoing scholarship research initiative undertaken by **Dr. Rehan Shah (School of Engineering and Materials Science)** from QMUL with current undergraduate student co-creators **Ms. Malmi Mahagamage** and **Ms. Meherun Soud**. Some of the mathematical content in these exercises was inspired by actual tutorial sheet questions from the Mathematical Tripos course taught at the University of Cambridge.

Sustainability Exercise Questions

1. **Pipeline Construction (SDGs: 7, 9, 14 and 15)**
2. **Environmental Disasters (SDGs: 6 and 12)**
3. **Simpson's Paradox (SDGs: 5 and 10)**

Tasks (will count towards formative engagement)

- **Engage and go through the resources** provided below
- **Complete the feedback survey below by end of SKEMP week Fri 7 Nov 2025 (17:00)** based on your engagement with these resources (responses will be monitored, checked and count towards formative engagement) (**note: feedback responses left blank, or with only punctuation or binary yes/no text responses will be discounted and will you have to the survey again**)
- **Complete the practice quiz below (released after the lecture in SKEMP week) by end of SKEMP week Fri 7 Nov 2025 (17:00)**, (responses will be monitored, checked and count towards formative engagement)

Ethics Exercise Questions

1. **Confronting Your Boss with Logic**
2. **Ethics of Crime Scene Investigation**
3. **Mathematics of Military Engagement**
4. **Mathematical Communication**

Before.....(pilot run)

Handout: Why do we need Ethics in Mathematics?

Notes to Instructor: This handout is a version of a handout that we distributed at a mathematics departmental open day for prospective students. It is written with the intention to be fun to read and to make students aware of where modern mathematics is used. It serves well as a leisurely supplementary reading for students if you decide to use some of the example sheet questions in this document.

Have you ever thought about the ethical issues that mathematicians and people using mathematics might encounter? Have you ever thought about all those issues that are specific and peculiar to mathematics?

Since primitive humans first began to use language and organise themselves socially, they have also counted and used simple arithmetic. It is a way of talking about and knowing about the world that is as much a part of what it is to be human as anything else that we might characterise as being an essential part of being human. Elementary mathematics – arithmetic, simple geometry, and the logic of problem solving have always been part of human activities and forms of knowledge of almost all human societies. But in the 21st century things are a bit different. High-end mathematics done by highly trained professional mathematicians is ubiquitous, and is unavoidable in a digital world. Most of the technology around us does not just use elementary arithmetic, algebra, and geometry – it often uses the most cutting-edge mathematics, the products of recent research and of the most technically sophisticated and abstract mathematics that humanity has produced. Mathematicians seem to be taking over the world, except that nobody has noticed. For example:

- The global financial markets are run by computer programmes that use mathematical models and mathematical analysis of financial products and markets. Modern financial mathematics is cutting-edge, highly developed, sometimes Nobel Prize winning and seriously hard. When the models fail, the economic consequences can be disastrous. A lot of mathematicians go and work for financial institutions, developing tools that come straight from research mathematics.

Exercise 1: Pipeline Construction

SDG Mapping: 7 (Affordable and Clean Energy), 9 (Industry, Innovation and Infrastructure), 14 (Life Below Water), 15 (Life on Land)

An oil company wants to build a pipeline connecting an oil platform to a refinery (on land). The coastline is straight. The oil platform is at a distance of D_1 from the coast. The refinery is on the coastline, a distance D_2 from the point on the coast closest to the platform. Building the pipeline will lead to a cost per unit length c_1 at sea and c_2 on land.

Calculate the optimal length for building the pipeline. What are the factors that need to be considered when providing a response to this question?

Exercise 2: Environmental Disasters

SDG Mapping: 6 (Clean Water and Sanitation), 12 (Responsible Consumption and Production)

A chemical accident took place near a small village in Peru. The region's local water reservoir has a volume V . The inflow and outflow of the reservoir is given by the flow rate r . Let $x(t)$ be the amount of mercury in the reservoir at time t . Assume that the reservoir was clean at the beginning i.e., $x(0) = 0$. Let $C(x)$ be the concentration of mercury flowing into the reservoir.

- a) Set up and solve a differential equation describing the concentration of the reservoir.
- b) What are some relevant questions you can ask about the concentration of mercury in the reservoir? How much does it matter?

Sustainability – Example Problem (Year 1)



Problem 3 – Simpson's Paradox

Mathematical topic: Probability

Contribution to [SDGs](#): Gender Equality (SDG 5), Reduced Inequalities (SDG 10)

Context of the problem: In a particular admissions cycle, a mathematics department observes a higher success rate for male applicants than for female applicants. To investigate whether this is the same across the two sub-departments of Pure and Applied Mathematics, the following year the department asks each applicant to give their preference for pure or applied mathematics (they are not allowed to be ambivalent) and records the resulting statistics as shown:

- Compare the success rates for male and female applicants that prefer applied mathematics, prefer pure mathematics and their success rates overall.
- What do you notice? Why is this possible? This is known as [Simpson's paradox](#).

Total:

	Applications	Successful
Female	300	30
Male	1000	210

Prefer applied:

	Applications	Successful
Female	270	18
Male	350	15

Prefer pure:

	Applications	Successful
Female	30	12
Male	650	195

Mathematical approach: This problem focuses on applying [probability](#) and [data analysis](#) to demonstrate [Simpson's paradox](#), a statistical phenomena in which a trend appears in several groups of data but disappears or reverses when the groups are combined. The question involves calculating and comparing the success rates for male and female applicants within each of the subgroups, which are Pure Mathematics and Applied mathematics, as well as for the whole group. By examining how group sizes and success rates contribute to combined data, the analysis provide a deeper understanding of the mechanics of the paradox.

Key sustainability insight: This question combines mathematics with real-world issues related to gender equality (SDG 5) in education and professional environments.

- **Gender disparities in STEM:** This question draws attention to gender disparities in mathematics and other STEM fields worldwide.
- **Broader inequalities:** It highlights how misinterpreting data can reinforce existing inequalities and shows the importance of transparency and accountability in data analysis, aligning with SDG 10.

This issue demonstrates the crucial role of mathematics in uncovering hidden disparities and supporting informed decision-making to promote fairness and equity.



Explore the 'Making Diversity Count' research project

The research project highlights the importance of representation in STEM, linking to our discussion of gender equality (SDG 5) and equity (SDG 10).



Discover biographical posters of STEM Champions

Learn about diverse mathematician and scientists who challenged stereotypes and inspire the next generation!

Sustainability– Example Solution (Year 1)



Problem 3 – Simpson's paradox

Mathematical topic : Probability

Contribution to SDGs : Gender Equality (SDG 5), Reduced Inequalities (SDG 10)

Calculations:

The success rates for male and female applicants based on preference (Applied or Pure Mathematics) and overall are calculated as follows:

	Prefer applied	Prefer pure	Total
Female	$\frac{18}{270} = \frac{14}{210}$	$\frac{12}{30} = \frac{4}{10}$	$\frac{30}{300} = \frac{10}{100}$
Male	$\frac{15}{350} = \frac{9}{210}$	$\frac{195}{650} = \frac{3}{10}$	$\frac{210}{1000} = \frac{21}{100}$

Observations:

[Simpson's paradox](#) is observed here: Females have higher success rates within each sub-departments, yet their overall acceptance rate is lower than males, **0.21 (male)** vs **0.1 (female)**.

Explanation:

- The largest male cohort (those who prefer pure mathematics – 650 applicants) has a high success rate of 0.3, raising the overall male success rate.
- However, the largest female cohort (those who prefer applied mathematics – 270 applicants) has a much lower success rate of 0.067, which drags down the overall female success rate.

This phenomena demonstrates the importance of examining sub-groups dynamics when analysing data to avoid misinterpretations.

Key questions to think about:

1. Analysing fairness in data aggregation:
 - How do different cohort sizes influence the outcomes?
 - What is the impact of [Simpson's paradox](#) on policy making in education?
2. Understanding sustainable systems
 - How can mathematics be used to promote equity and fairness in admission policies?
 - What steps can institutions take to ensure diversity and inclusivity in male dominant fields?
3. Sustainability in decision making
 - How does this analysis connect with broader sustainability goals, such as reducing gender equality (**SDG 5**) and ensuring quality education (**SDG 4**)?

Why these questions matter:

- Mathematical analysis supports sustainable problem solving by revealing hidden trends like Simpson's Paradox.
- In this way, it is possible to avoid misleading conclusions and promote the development of more inclusive, fair outcomes.
- These insights enable educators, policymakers, and researchers to incorporate equity and sustainability into their decisions, supporting diversity and sustainable development.

Ethics – Example Problem (Year 2)



Problem 1 - Confronting Your Boss with Logic

Topic: Propositional logic

Context of the problem: Your boss has given you a task. The task is well within your technical capability, but you are not sure whether it would be legal or ethical. You feel uneasy, but your boss tells you: *'If you don't do it, then someone else will.'*

Do you think that the boss' argument is cogent? Does that depend on who you are or what the project is? How would you answer your boss?

Mathematical approach : This problem can be mathematically examined by investigating the **reasoning** and **logic** behind the boss's statement.

- The statement *'If you don't do it, then someone else will,'* shows that someone else could replace you to do the task.
- Therefore, by using the tools of **propositional logic**, you can work out the likelihood for someone else to do the task instead of you.

Key ethical insight: Ethical decision making considers both logical reasoning and personal values.

Interpersonal integrity: It is essential to act morally as unethical behaviour could lead to unreliability.

Responsibility: Promoting ethical decision-making in the workplace can result in a positive environment to work.

This exercise allows students to delve into logical reasoning within the field of boolean algebra.

Ethics – Example Solution (Year 2)



Problem 1 – Confronting Your Boss with Logic

Topic: Propositional logic

Your boss has given you a task, however, you are unsure if it is legal or ethical. You feel uneasy, but your boss insists that *'If you don't do it, someone else will.'* Is this a valid question? Should you accept this reasoning?



This is a **flawed assumption**:

- The phrase assumes at least one person will carry out the task.
- This is not true as if no one else is available or willing to do it, the task may not happen at all.

Sock Analogy – to understand the problem



- Imagine a bag containing **1 red** sock and **9 blue** socks. There are **10 people** who pick a sock from the bag. The statement *'If you don't pick the red sock, someone else will'* is only **true** if **all 10 people** pick a sock.
- If **not all 10 people** participate, there is a chance that the **red sock may never be picked**. What is true instead is *'If you don't pick the red sock, someone else might.'*

This shows that just because an action can happen it does not mean it will happen. The probability of an event happening depends on how many people are actually willing to do it.



Therefore, going back to the problem:

- The correct phrasing should be *'If you don't do it, someone else might.'* So now we are accounting for the probabilities of the event's occurrence.
- If **many people can and want to do the task**, then it has a **higher probability** of occurring.
- However, if **few people** are capable of doing the task, then its **probability will be low**.

Ethical Considerations:

- Ethical decision making depends on evaluating its consequences not just its probability of occurrence.
- Justifying actions based on the belief that something will happen can lead to unethical decisions since it ignores the chance that it may not occur.

Key Questions to Consider:

- Does the assumed probability justify the ethical responsibility associated with this problem?
- If something unethical is presented as unavoidable, does that make it right?



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Ethics in Mathematics
Questions



Student Feedback Responses (Y1: n = 140, Y2: n = 188)

(1) Were you aware of "ethics/sustainability in mathematics" before coming across these problem exercises?

Sustainability: *"I was familiar with sustainability in engineering but not in mathematics. Every time I hear about sustainability, I tend to focus on the design aspects. These resources helped me understand the mathematics behind optimising designs."*

Ethics: *"I was aware of law in mathematics however this was the first time coming across the ethics side of the subject."*

(2) What did you find most enjoyable or interesting about these exercises?

Sustainability: *"The coloured border of both the problems and the solutions made the text easier to engage with. I particularly liked how the question combined mathematics with real-world issues such as gender equality in educational environments."*

Ethics: *"I found it interesting how mathematics can be used in real-world decision-making and the ethical dilemmas that arise from these applications."*

Student Feedback Responses (Y1: n = 140, Y2: n = 188)

(3) What suggestions, if any, do you have for improving these exercises?

Sustainability: *“One suggestion for improving these resources would be to **include more interactive elements**, such as **short videos or online simulations**, to help visualise.*

Ethics: *“The resources look great!! But I would suggest to **include these problems in the problem-solving sessions** because these problems help student understand the importance of ethical considerations in relation to mathematical topics.”*

(4) Would you like such exercise problems to be introduced in a classroom setting e.g. in lectures or tutorials?

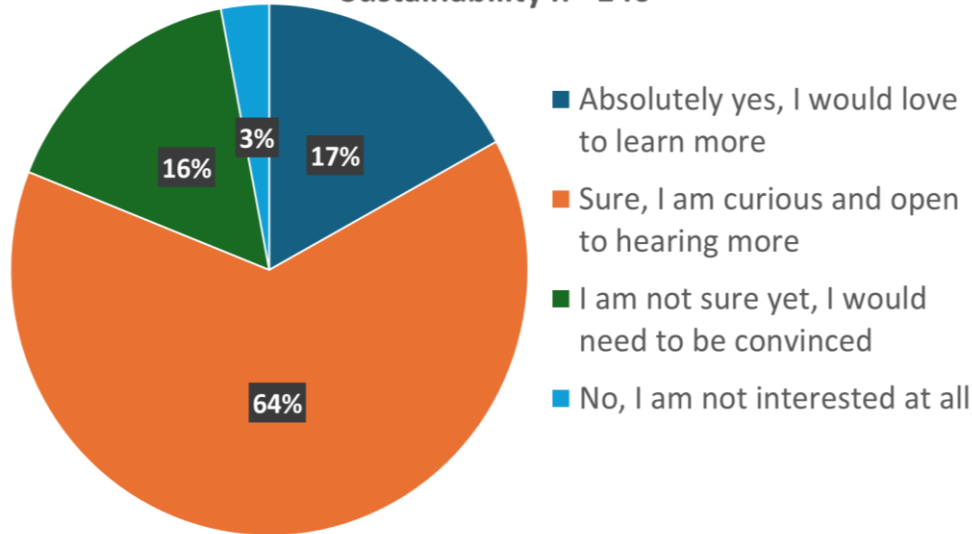
Sustainability: *“Yes. Introducing them in lectures would **help normalise the idea of diverse contributions to the field** and **make the curriculum feel more inclusive**.*

Ethics: *“I think it would be really helpful if, in our **problem-solving sessions**, we added an ethical question at the end of each scenario. Instead of just focusing on the calculations or technical details, these questions could ask us to think about the real-world impact of our decisions.”*

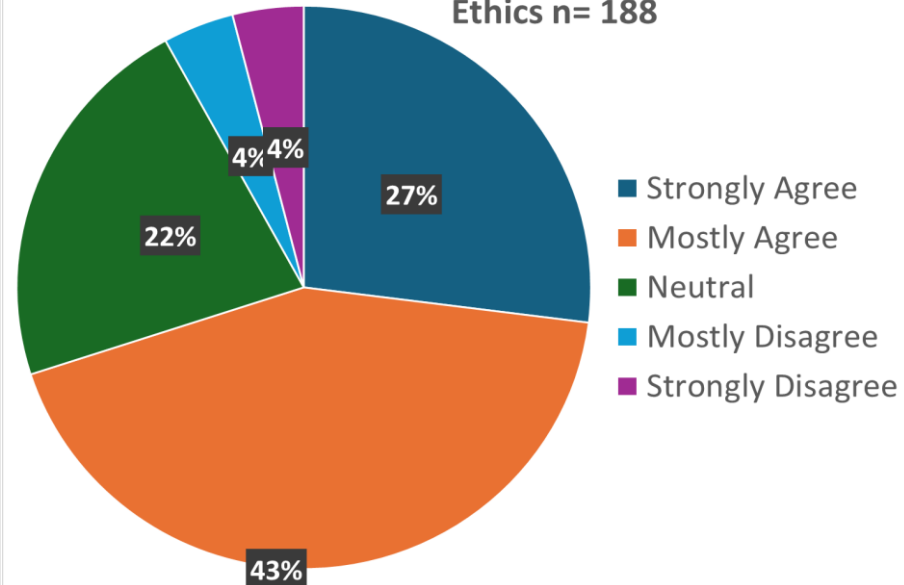
Student Feedback Responses (Y1: n = 140, Y2: n = 188)

(5) These resources made me want to learn more about sustainability/ethics in mathematics or its impact in the real world. Choose the most appropriate response.

Sustainability n= 140



Ethics n= 188



Formative Practice Quiz

- Introduced in 2025-26 implementation in **response to student feedback** from previous years
- Designed to **capture students' understanding** of sustainability and ethics in mathematics.

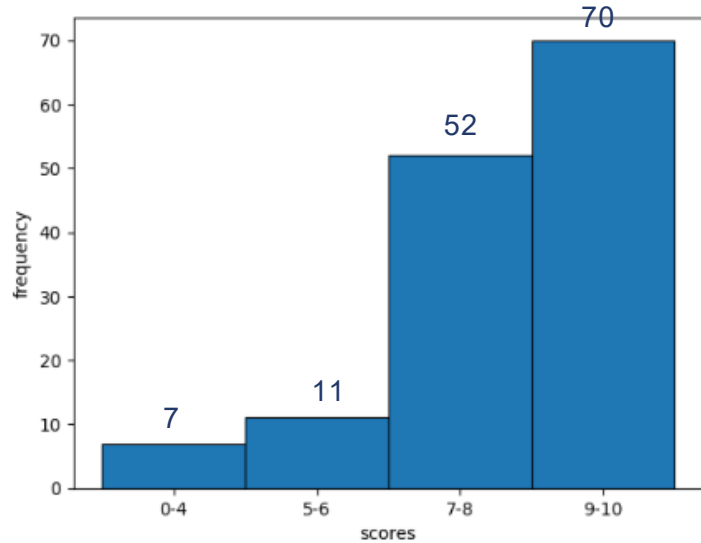
Which SDGs are linked to the '**Simpson's Paradox**' problem?

- a. Affordable and Clean Energy (SDG 7) and Industry, Innovation and Infrastructure (SDG 9)
- b. Reduced Inequalities (SDG 10) and Gender Equality (SDG 5)
- c. Decent Work and Economic Growth (SDG 8) and No Poverty (SDG 1)
- d. Clean Water and Sanitation (SDG 6) and Life on Land (SDG 15)

Which of these mathematical topics is most relevant to modelling the spread of a pollutant over time?

- a. Probability
- b. Differential equations
- c. Trigonometry
- d. Number theory

Quiz Performance (Y1: n = 140)



Score	0	1	2	3	4	5	6	7	8	9	10
Frequency	0	0	3	2	2	4	7	18	34	68	2
Relative Frequency	0%	0%	2%	1%	1%	3%	5%	13%	24%	49%	1%

- Quiz results **indicated a strong overall understanding** of the poster material.
- Out of 140 students, approximately **74%** achieved a score of 8 out of 10 and more.
- High scores **suggest students read the posters thoroughly** and engaged meaningfully.
- Overall, the practice quiz successfully **increased engagement** and reduced superficial interaction.

Analysis of Student Feedback

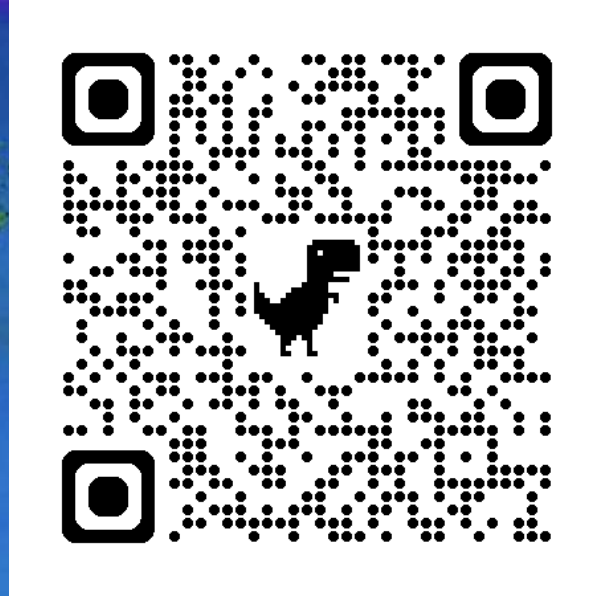
- Most students **were not aware of sustainability or ethics in mathematics** but found them interesting and relevant once introduced.
- Students **enjoyed** integration of sustainability and ethics in mathematics, through real-world scenarios
- Students **appreciated the clear layout, simple explanations, and step by step solutions**, which made the material easier to understand.
- Several students suggested adding more **videos, quizzes, visuals and discussion-based activities** to improve engagement and learning.
- Some liked the idea of using the material **in lectures or problem sessions**, while others preferred it as **optional content**.

Concluding Remarks and Next Steps

- As educators, we have a **responsibility to equip students with the tools to address global challenges** by embedding sustainability, societal and environmental issues into the mathematical curriculum.
- Next steps for project: **incorporate feedback** received from students and make tweaks to toolkit for future deployment.
- Prepare and **submit a case-study paper to a mathematics education journal (*MSOR Connections*)** to share the aims, approach, and outcomes of this project.

Thank you for your time!

Scan to access QMUL resources



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