Queen Mary University of London

THE LONDON STUDENT SUSTAINABILITY CONFERENCE 2025

# Embedding Sustainability in Mathematics?

# You must be joking!!!


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# Need for Sustainability in Mathematics

- Mathematics usually taught through **memorisation** and repetitive application of **formulae**.
- Often **limited emphasis on** the role of mathematics in addressing **sustainability challenges**.
- Existing curricula rarely highlight how mathematical tools contribute to **solving global issues**.
- Students struggle to recognise the connection between **mathematics and sustainability**.
- 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 **current undergraduate students**
- Teaching toolkit includes **handouts** on sustainability and visually appealing **posters** showcasing examples of real-world **mathematical problems linked to SDGs**.
- Pilot run implemented in a **first-year** undergraduate **applied mathematics module** for engineering students (400 students)
- Embedded as **asynchronous non-assessed** resources alongside course with a **feedback survey**

## Motivation

The mathematical exercises provided below are designed to raise sustainability awareness and imbibe transferable skills among undergraduate students in STEM disciplines as part of an ongoing scholarship research initiative undertaken by Dr. Rehan Shah from QMUL 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.

In addition to traditional mathematical content, each of the exercise questions below also contain some sustainability component to the problem, and in order to solve the problem fully, you will need to take into account this aspect and consider it as part of your solution.

“Solutions” to as many of these exercises as possible have been provided (released from Week 4). These include both a full exposition of the mathematical component of the question, as well as a discussion and incorporation of the societal and sustainability-related issues that are embedded in the question, which can serve as useful points for further discussion with Dr. Shah and your peers.

If you are more interested in this area and would like to engage in it further, please get in touch with Dr. Shah.

### Exercise Questions

1. **Pipeline Construction**
2. **Environmental Disasters**
3. **Simpson’s Paradox**

### Task

Please engage and have a look through these resources and then provide your feedback by completing the survey below by the end of Week 10 (Friday 29 November 2024).

**Introductory Handout - Why do we need sustainability in mathematics?** Completion

**Sustainability in Mathematics Exercise Questions**

247.8 KB

**Sustainability in Mathematics Exercise Solutions**

**Feedback Survey**

**Opened:** Monday, 23 September 2024, 9:00 AM **Closed:** Friday, 29 November 2024, 5:00 PM

## Handout – Why do we need sustainability in mathematics?

Despite the prevalence of the UN Sustainable Development Goals (SDGs) [1] since 2015, several reports and studies [2-4] have noted that the incorporation of sustainability within universities finds the greatest barrier in the field of teaching, with curricula often failing to address key environmental and ethical issues. Within the mathematical sciences, a report by the American Mathematical Society [5] also recommended that sustainability in mathematics should permeate education curricula for high-school and university students. This situation reflects the need for academics and educators in higher education to develop a toolkit of resource materials that can serve as a reference guide for the effective and systematic integration of sustainability into university mathematics curricula.

At policy level too, there is a growing consensus for integrating sustainability principles and practices into the curriculum and pedagogy of mathematics programmes so that students can learn about the environmental, social, and economic dimensions of sustainable development, to be equipped with the knowledge and skills to address sustainability challenges in their professional practice. The recently published QAA MSOR Subject Benchmark Statement [6] from March 2023 for example, explicitly highlights the need for mathematical science degrees to include technical problems where the motivation or context of the question stems from a sustainability issue.

Integrating sustainability into some university-level mathematical problems and exercises involves the following:

- **Interweaving into existing course materials:**
  Integrating sustainability within STEM courses is "largely a matter of providing context for what is already being taught", context that also makes the material already being taught seem "more relevant" [7]. The technique of "micro-insertion" described in the context of embedding ethics, can also be succinctly adapted for incorporating sustainability issues, in that these "are not add-ons; they work like an alloy, adding strength to the course without adding volume" i.e., they need not be perceived as components to be introduced in lieu of existing technical material.

- **Integration in a seamless and organic manner:**
  The inclusion of sustainability aspects into mathematical problems does require a great deal of care, thought and gradual experience as it might be done in a seamless and organic manner, without appearing to be artificial or contrived. The focus should be upon how students are engaging with these themes and not merely upon introducing sustainability as an add-on component to be taught [8]. Often this is avoided by ensuring that such concepts emerge naturally from the technical nature of the mathematics of the problem itself i.e., through an enlargement of the context of a problem by aligning it to a realistic scenario (see example problems below).

## Sustainability in Mathematics Exercise Questions

### 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?

# Student Feedback Survey Responses (n = 77)

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

*"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."*

*"**No**, I was **not aware** because this was **never taught in our schools**, and how mathematics can be related or used as a tool to tackle the goal of sustainability was never explored before.*

*"I am **surprised there is such term as "sustainability in mathematics",** I never thought it could exist. So, **no**, I wasn't aware of any sustainability matters before coming across"*

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

*"I found it **interesting how seamlessly sustainability is incorporated into the maths curriculum**, making it seam natural and relevant. I also liked **how the reflective aspect encourages students to consider the broader implications of their work**."*

*"I found it interesting the **mathematical techniques that can be used in real life** to measure issues faced and **provided quantitative data** that can then be used to **make changes**"*

*"I found that this would be **good to push for more critical thinking** and closer attention to detail."*

# Student Feedback Survey Responses (n = 77)

**(3) Did you find the solutions provided to be sufficient for understanding?**

*"Yes - They were succinct, while still providing **a short abstract** after the question **to those who are interested** (which I was) **with a clearer link to real life**."*

*"Yes, but I think this may be **more beneficial after all the concepts have been learned**. "*

***"**No - I would **need a picture/ diagram** to be able **to understand some of the questions**"*

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

*"I would add **an accompanied diagram** with the solutions to make it easier to understand it would be a **visual aid** as well as **links to similar questions** and learning material which I can do online and check my understanding*

*"It would be nice to have an **optional in-person session** for those interested in more, maybe **even a society** that runs sustainability related events."*

*"To improve these exercises, create questions that will use content that the majority of **first year students will know** from learning in prior years. For example, **any content learnt in A-level**."*

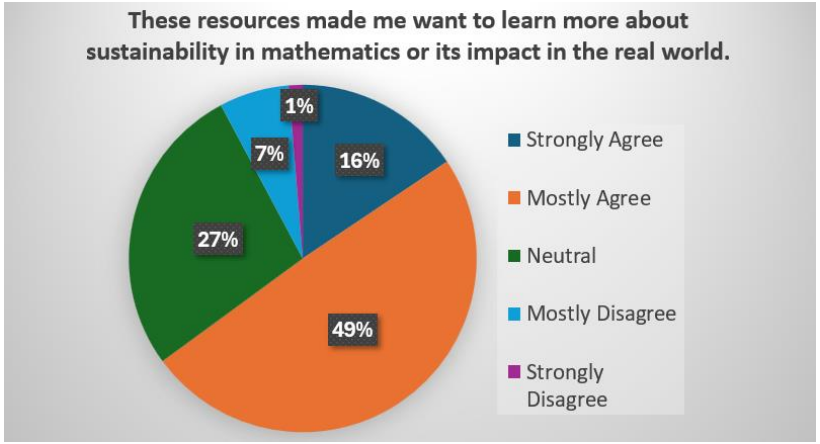
# Student Feedback Survey Responses (n = 77)

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

*"**Yes**, I think it would be good to introduce such exercise problems in **PBL sessions** and **worksheets provided for the week** so that we are able to get a better understanding on the topic covered."*

*"**Yes**, as they **make the learning more real** and potentially **easier to understand** as they are linked to a real-life context."*

*"I **wouldn't be fond** of such material to be presented in-class as it is not examinable content and might not be of high interest to all students. However, as already well done so by the professor, it should be strongly recommended to **read the material online** at **one's own pace and spare time**."*




**(6) These resources made me want to learn more about sustainability in mathematics or its impact in the real world. Circle the most appropriate response.**

*Majority (65%) agreed, with only 7% disagreeing and 27% remaining neutral, **highlighting strong engagement overall**.*

# Analysis of Student Feedback

- Most students **unaware of sustainability in mathematics** (only aware of them in design modules).
- Students **enjoyed** integration of sustainability and mathematics, through real-world scenarios
- Visual aids like **diagrams, videos,** and **additional links** were **recommended** to enhance understanding and promote independent learning.
- Many students supported introducing content **in lectures or tutorials**, some preferred keeping them **optional** to manage workload.
- Most feedback found the solutions clear and helpful, with **step-by-step** instructions and **short abstracts** linking sustainability to mathematics.

# Why do we need sustainability in mathematics ?

**"Since the introduction of the UN Sustainable Development Goals (SDGs) in 2015, universities have struggled to integrate sustainability into mathematics education. "**

**Why is this a challenge for universities?**
Universities struggle to incorporate sustainability in mathematics since it is frequently viewed as 'abstract', 'theory-driven subject with few direct connections to real-world issues.

**So, this needs to change!**
According to a report from the American Mathematical Society, sustainability should permeate mathematics curricula at high school and university levels. We have been applying sustainability in mathematics unconsciously e.g., when tackling energy optimisation. It is crucial, that students increase their awareness to enhance their mathematical and sustainability understanding.

**Why should STEM programmes help students understand environmental, social, economic issues related to sustainability development?**
These fields play a crucial role in sustainability-related issues. By integrating sustainability, STEM education can provide students with the skills necessary to create innovative solutions that will enable a sustainable future to be achieved..

## How can we integrate sustainability into university-level mathematics?

- **Interweaving into existing course material:**
Sustainability can be integrated into STEM by incorporating real-world relevance to current settings. The 'micro-insertion' strategy strengthens the curriculum without replacing fundamental content.

- **Integration in a seamless and organic manner:**
Integrating objectives sustainability into mathematics requires significant consideration to ensure that it feels natural rather than artificial. The primary focus should be on student engagement, with sustainability occurring naturally from the mathematical principles rather than as an add-on component. This can be attained by linking problems with real-world scenarios

- **Subjective and reflective aspects:**
Sustainability questions will frequently involve open-ended discussions, which encourage deeper reflection from both students and instructors. Unlike the objective problems with clear answers, solutions can vary and evolve over time.

- **Links with the UN Sustainable Development Goals**
Sustainability concepts in math problems can be linked to the 17 UN SDGs (shown below), giving students with a more holistic view of sustainability within STEM. This helps connect technical learning to real-world sustainability objectives.

## What are UN sustainability development goals?

The Sustainability development Goals (SDGs) represent a global initiative to eradicate poverty, safeguard the environment, and enhance the well-being and future-prospects of people worldwide. Adopted by all United Nations Member States in September 2015, the SDGs area key component of the 2030 Agenda for Sustainable Development, which outlines a 15-year framework for achievng these goals and their associated targets (United Nations, 2022).


**References:** United Nations (2018). Sustainable Development Goals (SDGs) and Disability | Division for Inclusive Social Development (DISD). [online] social.desa.un.org. Available at: https://social.desa.un.org/issues/disability/sustainable-development-goals-sdgs-and-disability.

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# Examples of mathematical problems with embedded sustainability

**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:

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 |

- 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.

**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 undercovering 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!

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# Problem 3 Solution- Simpson's Paradox

**Problem 3 – Simpson's paradox**
Mathematical topic : Probability
Contribution to SDGs : Gender Equality (SDG 5), Reduced Inequalities (SDG 10)

This problem demonstrates 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. It also highlights gender disparities in mathematics admissions, enhancing the understanding of systematic inequalities.

**Calculations:**
The success rates for male and female applicants based on preference (Applied or Pure Mathematics) and overall are calculates 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 researches to incorporate equity and sustainability into their decisions, supporting diversity and sustainable development.

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# Concluding Remarks and Next Steps

- **Faculty support is critical** for integrating sustainability in technical modules, but this can be hard. (responses such as "*we're an engineering department; how can we incorporate sustainability into our course?"*).

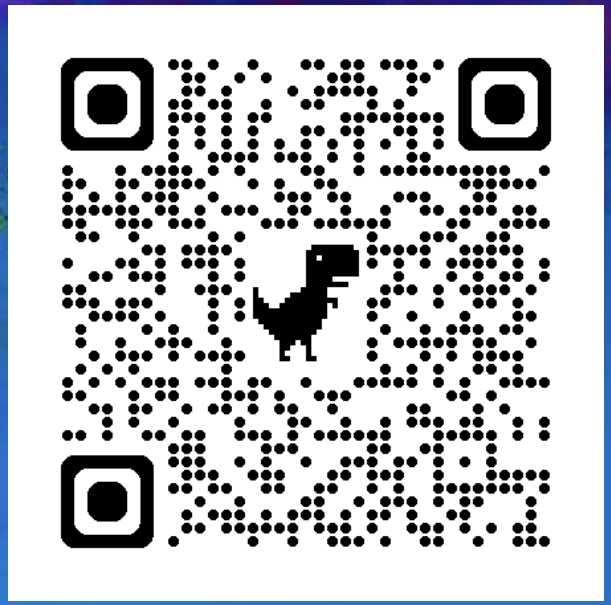
- As educators, we have a **responsible to equip students with the tools to address global challenges** by embedding sustainability, societal and environmental issues into the mathematical curriculum.

- Next steps for project: **incorporate feedback** received from students and make necessary tweaks to toolkit for future deployment

- Will present at **British Conference for Undergraduate Research** (BCUR) in April 2025 at University of Newcastle.

# Thank you for your time!

## Scan to access QMUL resources



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