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Mathematics in Engineering Education as a catalyst for Diversity, Sustainability, and Global Impact

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Abstract

Mathematics is considered a vital part of engineering education; however, it often presents challenges in creating a more inclusive profession by placing barriers to entry. Yet practicing engineers in industry often report that the maths they learnt (or suffered) as students is rarely of practical use beyond university. In addition, there is evidence that the most common approaches to teaching and learning maths is not effective in creating mathematical thinkers. These three dimensions represent both an opportunity and a necessity to rethink and reshape our approaches to mathematics teaching and learning.

Addressing the barriers to mathematics at entry, such as unequal prior preparation and perceptions of accessibility, is essential for broadening participation and fostering gender and wider diversity in engineering. In this paper we discuss the practical issues of reducing the usual requirements for mathematics at entry, and how this single step has impacted the teaching and learning in our engineering programmes. The links to global issues of women in STEM and the local questions for underrepresented socioeconomic groups in higher education engineering are also considered.

Innovative approaches to teaching mathematical problem-solving—emphasizing real-world relevance and contextualized learning—can better engage engineering students. By embedding mathematics into engineering problem-based learning and integrating sustainability and social dimensions, students develop a deeper understanding of mathematics and how engineering solutions intersect with global challenges, such as climate change and social inequities.

We also present how by identifying clearly what is meant by mathematical thinking and fluency, we might be better able to equip our students with a mathematical education more suited to becoming effective engineers. The focus on fluency in mathematics reading and interpretation, and mathematical thinking characterized by critical reasoning, creativity, and adaptability, equips future engineers to navigate complex, interdisciplinary problems. These cognitive skills are essential for achieving the United Nations Sustainable Development Goals (SDGs), which demand equitable as well as innovative solutions. A mathematics curriculum that prioritizes inclusivity and relevance can not only mitigate attrition among diverse cohorts and so address the SDGs for meaningful work and gender equality, but it can also enhance the societal impact of engineering practice by cultivating professionals more attuned to global needs.

This approach to mathematics in engineering education could provide engineers better prepared to meet the SDGs through solutions that are not only technically sound but also socially and environmentally responsible. Ultimately, reframing mathematics as an accessible, meaningful, and inclusive discipline has the potential to redefine engineering education, empowering a new generation of engineers to address global challenges with empathy, equity, and effectiveness.

1 Introduction

Mathematics is often considered a vital part of engineering education. But despite its reputation for neutrality, mathematics functions as a significant structural gatekeeper in STEM education and careers. A growing body of interdisciplinary research highlights how culture, pedagogy, and institutional role of mathematics contribute to the persistent underrepresentation of women and other marginalised groups in STEM fields, and so undermining progress on several key Sustainable Development Goals (SDGs).

1.1 Practical challenges and issues

There are three dimensions to the practical issues of delivering mathematics for engineers which are addressed in this paper:

- Mathematics as a barrier*:* The requirement for mathematics presents challenges in creating a more inclusive profession by placing barriers to entry,
- Innovative Teaching of Mathematic: There is evidence that the most common approaches to teaching and learning maths are not effective in engineering education.
- Authentic mathematics for engineering: Ensuring alignment between mathematics for engineering programmes and mathematics in practice.

These three dimensions represent both an opportunity and a necessity to rethink and reshape our approaches to mathematics teaching and learning for engineering.

1.2 Gendered and Socio-economic Implications for STEM and the SDGs

A fourth and more complex dimension is related to the implications of a different approach to mathematics for the SDGs. We start by noting that mathematics in education is structurally biased: the usual approach to maths teaching and learning includes examinations, prerequisite-heavy course structures, and early stereotypical assumptions of what being "good" at maths means (Mendick, 2005). This systematically disadvantages women students and those from marginalised socioeconomic backgrounds. As a result, mathematics often exacerbates existing inequalities, in direct conflict with SDG4 Quality Education, that calls to ensure equal access for all women and men to all education, and elimination of gender disparities in education. Rethinking what is the role of mathematics in engineering education may provide a way to better access to STEM, in particular engineering, for all.

2 Mathematics as a Barrier

Addressing the barriers created by mathematics, such as unequal prior preparation and perceptions of accessibility, is essential for broadening participation and fostering gender diversity in engineering.

2.1 Implications of Mathematics as a Pre-requisite to Engineering Programmes in the UK

In the United Kingdom, mathematics serves as a high-stakes filter for entry into many STEM degree programs, most notably engineering. The A-level maths qualification is often positioned as a non-negotiable prerequisite for university-level engineering, creating a rigid barrier that disproportionately excludes certain groups of students. While nearly half of all A-level entries are female, only about 37% of those in mathematics, and 26% in physics, are from girls (JCQ, 2024). This disparity compounds at each stage of the STEM pipeline (IOP, 2018). Access to mathematics is also often mediated by socioeconomic factors. Disadvantaged pupils are more likely to have suffered from a lack of maths teachers in the early stages of secondary (e.g. Owen & Ferda, 2024) and less likely to get a good GCSE pass (EEF, 2024) or to be offered Further Maths (Roylan, 2017). Requiring A-level, and/or early high achievement, in mathematics entrenches inequalities and narrows the engineering pipeline.

Proposals to consider more flexible entry routes into engineering, including allowing applicants with low mathematics achievement, even with contextual or additional support, have generated significant debate (Andrews & Clarke, 2017). Critics argue that these risk diluting standards, or cause students to fail at later stages, but there is evidence that this is not so (Goodhew, 2017). Clearly it is preferable to address the root causes that lead some school pupils to not have the same opportunities in maths; but while we await the radical changes necessary in the UK's education system, say as proposed by the Royal Society's Future of Education project (2022), removing maths as a prerequisite could democratize access and participation and so increase the available talent for engineering, maybe addressing gender imbalance and workforce shortages in UK's engineering.

2.2 Gender and Mathematics

Despite its reputation for neutrality, mathematics functions as a significant structural gatekeeper in STEM education and careers. A growing body of interdisciplinary research highlights how the culture, pedagogy, and institutional role of mathematics contribute to the persistent underrepresentation of women in STEM fields, which undermines progress on several key Sustainable Development Goals (UNESCO, 2020).

Mathematics is often framed as objective and meritocratic, yet it is a domain that is aligned with traits seen to be masculine, and its use as a gatekeeping subject for engineering reinforces gendered patterns of exclusion (Boaler, 2016; Leyva, 2017). These associations can foster stereotype threat, reduce mathematical self-efficacy, and discourage identification with STEM among girls and women (Hargreaves, Homer, & Swinne, 2008). Although in general there is no significant gender differences in maths performance in early maths, girls and women continue to be significantly underrepresented in post-16 STEM pathways because of this cultural misalignment (Archer, *et al*., 2023).

2.3 Perceptions of Engineering at Access

Removing mathematics as a strict prerequisite for engineering degrees has the potential to disrupt cultural barriers. It may lead to changed public perceptions of engineering to better align education with the interdisciplinary and societal demands of engineering today (Royal Academy of Engineering, 2020).

By removing the requirement for mathematics at entry and offering integrated support, institutions can reduce barriers without compromising learning outcomes as reported by (Goodhew, 2017; Archer, *et al*., 2023). This is the approach taken by NMITE. By allowing entry to applicants with a diversity of educational and socioeconomic backgrounds, NMITE is repositioning engineering as a socially meaningful, problem-solving, collaborative profession where multiple intelligences and a range of competencies are valued. Early indications are that NMITE is attracting students with strengths beyond traditional mathematics, including those from arts, humanities, and social science backgrounds.

3 Innovative Teaching of Mathematics

Innovative approaches to teaching mathematical problem-solving, in which real-world relevance and contextualised learning is emphasised, can better engage engineering students, but also enable students develop a deeper understanding of mathematics for complex engineering solutions.

3.1 Reframing Mathematical Thinking and Fluency

Removing rigid maths prerequisites and integrating numeracy development across the curriculum may provide more space to develop other so-called soft skills, e.g. communication, reasoning, adaptability, creative problem-solving competencies often neglected in mathematically exclusive pathways.

By being clearer about what is meant by mathematical thinking and fluency, we might be better able to identify what we need to teach. We can do this by:

- Redefining mathematics for effective engineering practice
- Focusing on fluency in mathematics reading and interpretation
- Encouraging "higher level" mathematical thinking skills: critical reasoning, creativity and experimentation, and adaptability.

3.2 Levels of Mathematical Skills

At NMITE, Jan De Lange's three types of mathematical thinking, as described by Goold and Devitt (2012) have been adapted to describe 4 levels of mathematical skills (MS0-3 in the figure below).

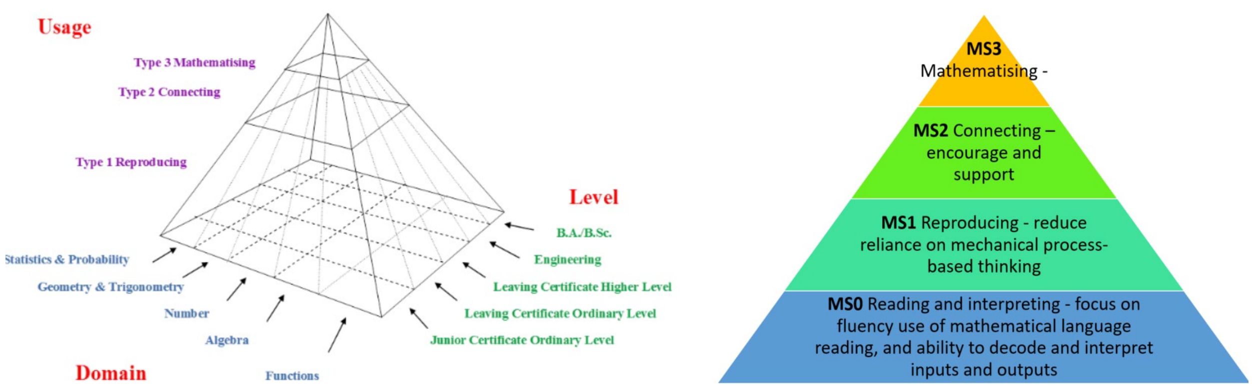

Figure 1 De Lange's Pyramid (Goold & Devitt, 2012) *and NMITE Maths Skills*

The aim is to make more visible the very low level of essential mathematical fluency of reading and interpreting mathematical language, and the highest level of *mathematising*, i.e. fitting appropriate maths models. The former skill is often assumed at the start of engineering programmes, but at NMITE, we are attempting to address all gaps at this level of skill from the start. In addition, we aim to promote mathematical curiosity as part of professional life-long learning, various reasoning tools aligned to Boaler's *math-ish* concepts (2024), and the use of tools, including generative AI tools, software and diagrams, to aid in understanding how to experiment with and apply mathematics to engineering. With this new emphasis and clarity, we aim to equip our students with a mathematical education more suited to becoming effective engineers.

3.3 Different Pedagogical Practices

The conventional approach to maths training for engineers puts emphasis on practiced techniques applied to known problems, i.e. *procedural knowledge* (Tall, 1991), prioritizing speed, procedural correctness, and individual problem-solving. This both alienates students whose strengths are not reflected in conventional assessments (Gutiérrez, 2008; Leyva, 2017; Archer, *et al*., 2023) and does not prepare engineers to apply maths in new situations and for real problems. In addition, there is much work, both theoretical and practical, to indicate that different practices can support better learning outcomes (Tall, 1991; EEF, 2022). Encouraging a deeper appreciation for exploration with maths, and trying different "messy" approaches, for example as taken at NMITE and described by Knight *et al.* (2024) and Ward *et al*. (2025), will foster more adaptive, interdisciplinary graduates prepared for real-world engineering.

4 Defining 'Authentic' Mathematics

The mismatch between mathematics taught in engineering programs and the mathematics utilized in real-world engineering practice is a significant concern. Employers increasingly prioritize soft skills such as communication, customer service, problem-solving (EngineeringUK, 2023), and ethics, teamwork, resilience (Fleming, Klopfer, Katz, & Knight, 2024); these are competencies often neglected in mathematically intense programmes. Practicing engineers often report that the complex mathematical concepts they learned as students are rarely directly applied beyond the academic setting. In addition, many engineering challenges, climate adaptation, health technologies, and infrastructure design, require creativity and systems thinking (Trevelyan, 2014). This calls for a rebalancing of curricula.

4.1 A different view of mathematics

A more authentic approach to mathematics in engineering education would emphasize:

- Real-world relevance and contextualized learning
- Mathematical thinking embedded in engineering problem-based learning
- Sustainability and social dimensions.

By developing a deeper understanding of maths (or *mathematising*), students can appreciate the practical value of maths in supporting solutions to complex, real problems. By revising and rethinking mathematics for engineering programmes, the expectation is that this will:

- Mitigate attrition among diverse cohorts
- Ensure that the mathematical skills taught are those of relevance to practice
- Enhance the societal and global impact of engineering practice.

4.2 Reframing engineering

Engineering is often seen as a mathematically intensive, highly technical discipline, and as noted this deters students who are drawn to creativity, design, or social impact. This also means that engineering can be elitist, particularly in cultures where high *science capital* is only found in high socio-economic groups.

By rethinking the role of mathematics in engineering education, engineering can be repositioned as a field that values multiple intelligences, including communication, systems thinking, design, and ethical reasoning. This aligns with real-world engineering, which is increasingly interdisciplinary and societal in focus (e.g. sustainability, humanitarian engineering, digital design). In addition, this re-thinking could challenge the idea that only an academic elite can become engineers and will better prepare student engineers to meet the SDGs through socially and environmentally responsible solutions.

4.3 Real mathematics for real engineering

By emphasizing real-world relevance and contextualized learning we not only hope to better engage engineering students (Tsui & Khan, 2023), but also support students to develop a deeper understanding of mathematics as an engineering tool, which should, in turn, enable higher mathematical skills. At NMITE we are working towards embedding mathematics into engineering problem-based learning that integrate sustainability and social dimensions or address global challenges (e.g., climate change, social inequities, pollution and waste). We are taking the following as underlying assumptions:

- Challenge engineering teaching that is maths-led rather than problem-led.
- Focus on understanding, over and above application of a technique or procedure.
- Increasing confidence in tackling new problems.

Emphasizing breadth and understanding could align better with engineering roles that require critical thinking across domains, such as environmental engineering, systems design, and public infrastructure.

Early indications from the outcomes of NMITE's first graduates is that this approach may lead to more adaptive, interdisciplinary graduates better prepared for real-world engineering challenges.

5 Implications for the Sustainable Development Goals

A final note on the implications of rethinking mathematics for engineering for the global SDGs: gender and social inequities in mathematics access and success restrict the diversity of perspectives in STEM. Although there are few direct, large-scale empirical studies specifically investigating the relationship between levels of women's participation in science and engineering with a country's overall SDG performance, there do exist lines of evidence and analysis to suggest a positive correlation between high levels of women in STEM and a country's level of achieving the SDGs, both in theory and in practice (Bello, Blowers, Schneegans, & Straz, 2021). Diverse and inclusive STEM participation is not only a social justice imperative, but also a prerequisite for achieving Agenda 2030.

Maintaining the current conventional approaches to mathematics in engineering deprives engineering of diverse perspectives that are essential to innovation and sustainability. Rethinking is vital for SDG5 (gender equality) as well as SDG4. Ensuring wider diversity in engineering will increase our capacity to address multifaceted global challenges, including health (SDG3), climate change (SDG13), and industry and innovation (SDG9).

6 Concluding remarks

To advance gender equity and reduce elitism in engineering, and meet the broader global goals of sustainable development, we must critically reassess the role of mathematics in engineering education. Rethinking mathematics in engineering requires, at the very least, the following three steps:

1. reforming gatekeeping mechanisms
2. clarifying what is meant by mathematical skills for engineers

3. reimagining the curriculum to embed *authentic mathematics.*

It is worth repeating that reducing or removing mathematics as a rigid prerequisite to entry to engineering programmes is not about "lowering standards"; it is about broadening the lens through which engineering talent is recognized and nurtured. The second and third steps ensure that the mathematics teaching and learning in engineering is informed by the ultimate ambition: engineers who can use mathematics to its best advantage. At NMITE we are working towards teaching that

- Emphasises and addresses real-world relevant mathematics skills.
- Embeds mathematics in our engineering problem-based learning.
- Integrates sustainability and social dimensions into mathematics education.

These steps and considerations, we hope, will lead to better outcomes for our graduates. But more than this, mathematics could evolve from a barrier into a bridge to enable all to participate fully in the construction of a more equitable and sustainable future. These changes have the potential to recast engineering as an inclusive, creative, and socially responsive field. Thinking differently about mathematics for engineers may, in a very practical sense, better reflect the actual demands of engineering careers today, as well as better support a new generation of engineers able to address global challenges with empathy, equity, and effectiveness. This will be crucial for meeting the UK's workforce needs and advancing the UN's SDGs.

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