Futureproofing the Education of Non-Traditional Higher Education Entrants: Embedding Mathematics into Engineering Curricula

Knight, B.[1], Pyakurel, P.[1], and Souppez, J.-B. R. G.[2]

1 - New Model Institute for Technology and Engineering (NMITE), UK, 2 – College of Engineering and Physical Sciences, Aston University, UK.

Abstract

Mathematics is fundamental to engineering education. However, higher education engineering courses have struggled to make mathematics accessible to students, with a reported disconnect between theory and practice. While a number of approaches have attempted to bridge this gap, there remains an entry requirement for mathematics, and dedicated modules. Consequently, to widen participation, better evidence the applications of mathematics and support students, we present a paradigm shift for mathematics in engineering education. First, we analyse a case where mathematics entry requirements are removed, and no dedicated mathematics modules are present. Second, mathematics is embedded in the curriculum with focus on wide applications and physical interpretations. Our results show that, while a difference exists between students with and without mathematical background in the first year of their courses, it is suggested this is no longer the case by the second year, showcasing the effectiveness of the proposed approach.

Keywords

Mathematics, Engineering Education, Widening Participation.

Introduction

Mathematics plays a vital role in engineering, as evidenced by its presence in the Accreditation of Higher Education Programmes (AHEP 4) learning outcomes (Engineering Council, 2020a), the Washington Accord graduate attributes (International Engineering Alliance, 2024), and the Chartered Engineer (CEng) competencies (UK-SPEC) (Engineering Council, 2020b). Traditionally, mathematics in engineering education is taught as a first-year module, often acting as a pre-requisite for further engineering modules involving the application of mathematics (Klingbeil et al., 2004). This heavily theoretical approach results in a lack of engagement from students, who perceive mathematics as very repetitive and overly theoretical (Noskov & Shershneva, 2007), particularly in the first year of higher education (HE), where students have reported not perceiving the importance of mathematics to engineering (Flegg et al., 2012).

Consequently, a more applied approach to mathematics in engineering education has emerged. The Wright State University (WSU) model (Klingbeil et al., 2004) advocates for a just-in-time approach to mathematics, to directly support practical applications in other, more applied, modules. A more authentic approach has been suggested by Herrington & Herrington (2008), with strong support for problem-based learning (Sadler, 2008). More recently, innovative ways to teach mathematics in engineering education and enhance student engagement and outcomes has included virtual labs (Cheong et al., 2018), and integration as part of design projects (Abou-Hayt et al., 2019). These, however, continue to rely on dedicated mathematics modules, which have implications in terms of entry requirements. To alleviate these, mathematical bridging courses, aimed at facilitating transition from secondary to tertiary education have been developed (Rolf et al., 2018).

However, as long argued by Booth (2004), any approach to teaching mathematics to engineers is rendered ineffective for as long as the students are unable to realise the importance of mathematics to their studies and careers. Moreover, strict entry requirements in mathematics for engineering curricula may prevent the widening of participation and access to HE. Consequently, to support the access of non-traditional HE entrants into engineering education, and foster inclusive education for all, a paradigm shift is needed in mathematics education for engineers.

The New Model Institute for Technology and Engineering (NMITE) is a UK HE institution that stands out in its approach to mathematics in its engineering courses. It is one of only two UK Universities not to have mathematics as an entry requirement. Moreover, NMITE does not feature any dedicated module for mathematics, or examinations. Mathematics contents are wholly embedded in the curriculum, with an industry-driven, challenge-based approach that employs the need for mathematics in these challenges as the motivation for embedded delivery. In this paper, the NMITE approach to embedding engineering mathematics in the curriculum and associated outcomes is presented.

Mathematics has historically focused on solving techniques in engineering education. But purely solving mathematical equations has been made at the expense of providing physical interpretations of the mathematics in engineering and a qualitative understanding of the utilised mathematics. Students may become proficient in solving repetitive equations but lack a contextualised understanding of the applications of mathematics. Consequently, they can only apply the mathematics in very limited contexts, i.e., the specific contexts they were taught.

Therefore, there needs to be a greater onus on physical interpretations and qualitative understanding of mathematics, and less focus on solving techniques, to foster futureproof learners. This is even more true given the availability of both software and generative artificial intelligence, that can effortlessly solve complex equations.

As such, the onus should be placed on developing students' mathematical thinking ability. This should entail taking natural or engineering processes and translating them into mathematical language. Moreover, an understanding of the assumptions made when developing equations and interpretations of results produced by software is essential, particularly for a more integrated approach to engineering. Based on this ethos, we present a new paradigm for mathematics in engineering education, based on a case study of NMITE, and argue that this does not only foster better student learning and outcomes, but also supports the widening of participation in engineering in higher education.

A New Paradigm

The NMITE paradigm focuses on applications of mathematics in engineering. Emphasis is placed on physical interpretations of mathematics to help students understand broad applications of a given mathematical concept in different engineering scenarios. Key aspects of mathematics delivery at NMITE include (Knight, 2024a, Pg 6):

- Engineering-led – Mathematics is not typically taught in its abstract form (i.e. is taught in-context with engineering concepts and applications)
- Concept-led – Emphasis on students learning mathematical concepts rather than their ability to reproduce techniques
- Open-ended – Emphasis on students demonstrating how they rationalise and solve problems in their own way over finding 'the correct answer'

The NMITE paradigm is meant to help engineering graduates make sound judgements on the level and depth of mathematical analyses required on a case-by-case basis for different real-life engineering situations.

Indeed, it could be argued that a traditional focus on mathematical technique and mathematics as an abstract or other-worldly concept, divorced from reality and real-world problem-solving, may undermine would-be engineering undergraduates from pursuing engineering. In the UK at age 16, students may be expected to foresee their post-18 trajectory and, should a student make the 'mistake' of not choosing mathematics at AS/A-level (Framework for Higher Education Qualifications [FHEQ] level 3), they are disqualified from pursuing engineering at the overwhelming majority of UK HE providers.

Moreover, this may be seen as particularly disadvantageous for the female student demographic, considering the gender disparity in uptake of FHEQ level 3 mathematics qualifications. The Advanced Mathematics Support Programme (2022), for example, found that among students taking AS/A-level mathematics and further mathematics, the proportion of female students was 40% and 30% respectively.

The assertion that an alternative approach to the embedding of mathematics in engineering education can support widening participation has yet to be fully researched and validated. However, at NMITE, considered an ‘emerging leader’ in engineering HE (Graham, 2018; Hitt et al., 2020), new insights are developing with regards to its strategy of recruiting students without an FHEQ level 3 qualification in mathematics.

Upon conducting a non-parametric analysis of student outcomes and attainment against equality, diversity and inclusion (EDI) data, evidence was shown for attainment effects at FHEQ level 4 depending on whether students had a level 3 qualification in mathematics (Knight, 2024b). However, the analysis did not provide evidence for such effects in student attainment at FHEQ level 5.

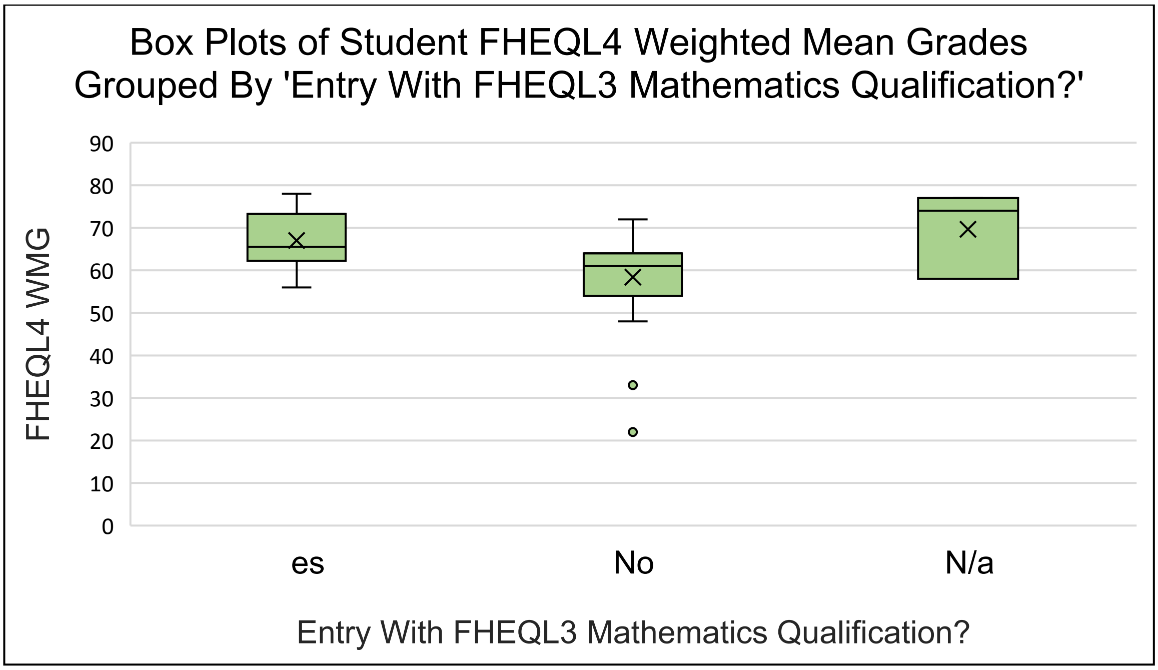

Figure 1. FHEQL4 Distribution. Distribution of FHEQ level 4 weighted mean grades among NMITE students grouped by ‘entry with FHEQ level 3 mathematics qualification?’. Data from May 2023.

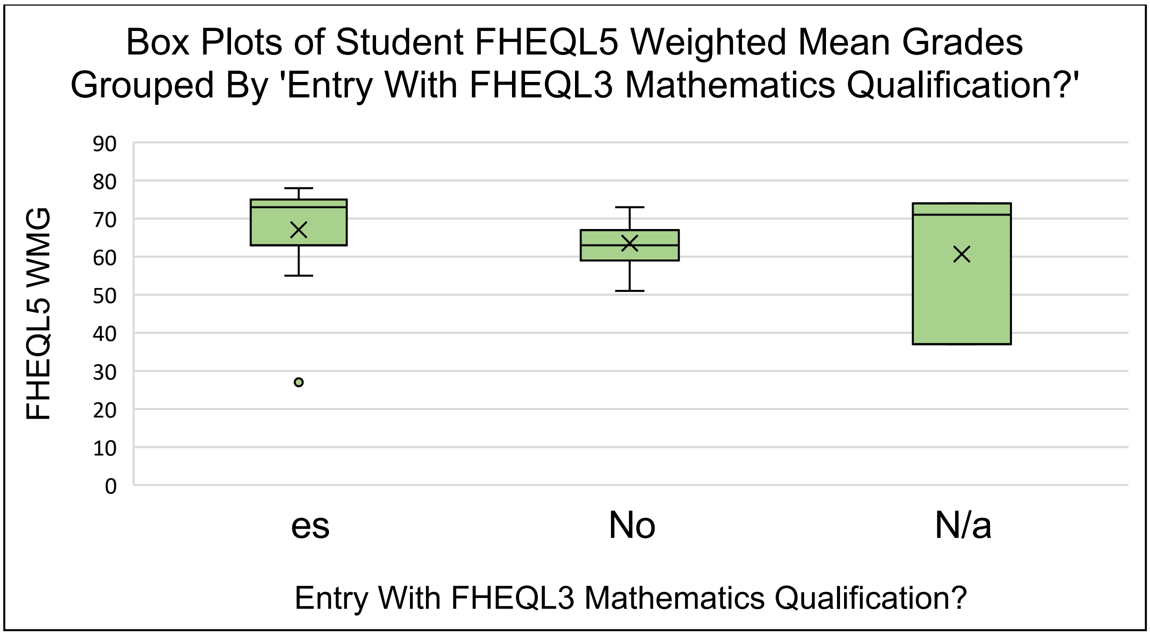

Figure 2. FHEQL5 Distribution. Distribution of FHEQ level 5 weighted mean grades among NMITE students grouped by 'entry with FHEQ level 3 mathematics qualification?'. Data from May 2023. **Table 1. Non-Parametric Results Summary.** Summary table of non-parametric statistical tests conducted on NMITE student outcomes, attainment and EDI data, where 'Level 3 Maths Qualification' was the independent variable (Knight, 2024b).

1**Test Type**	**Dependent Variable**	**Significance Level**	**Reject/Fail to Reject Null Hypothesis**	**Research Question**
Chi-squared	Student Status	0.258	Fail to Reject	Is there evidence to suggest a dependence between student status (registered / leave of absence / withdrawn) and whether a student has an FHEQL3 maths qualification?
Kruskal-Wallis	FHEQ Level 4 Weighted Mean Grade	0.003	Reject	Is there evidence to suggest a dependence between whether a student has an FHEQL3 maths qualification and FHEQL4 weighted mean grade?
Kruskal-Wallis	FHEQ Level 5 Weighted Mean Grade	0.138	Fail to Reject	Is there evidence to suggest a dependence between whether a student has an FHEQL3 maths qualification and FHEQL4 weighted mean grade?

Naturally, given FHEQ level 4 does not contribute to students' final degree classifications, it could be argued that this is a useful period for students to fail, and for a 'levelling of the playing field' to take place within student cohorts. Given that attainment effects appear to cease at level 5, this may suggest that such a ‘levelling of the playing field’ takes places at NMITE as a function of its teaching and assessment practices through FHEQ level 4.

Conclusions

This paper proposes a novel approach to mathematics delivery in engineering by illustrating a case study of New Model Institute for Technology and Engineering (NMITE). The underlying principles of the embedding of mathematics into NMITE’s emerging engineering curriculum de-emphasises a traditional reliance on mathematical techniques, and instead emphasises its physical interpretations and applications. Key aspects of NMITE’s mathematical teaching and learning delivery include ‘engineering-led’, ‘concept-led’ and ‘open-ended’.

Acknowledging the need for further research and validation, the analysis in this paper gives an indication that NMITE’s model may be succeeding in mitigating initial attainment disparities between students with and without an FHEQ level 3 qualification in mathematics. By extension, the results shed light on the possibility of removing FHEQ level 3 mathematics qualification requirements for entry onto degree-level engineering programmes. It is anticipated these findings may be particularly helpful in widening participation, especially among the female student demographic.

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