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AN INNOVATIVE APPROACH TO THE DEVELOPMENT OF CROSS-DISCIPLINARY CURRICULUM AND ASSESSMENT IN UNDERGRADUATE ENGINEERING EDUCATION

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Abstract: Cross-disciplinary courses in university engineering programmes provide supplemental knowledge that core technical subjects alone cannot provide. However, studies have shown that engineering students do not interact with such courses even when they appear complex, which affects educational success. Therefore, this study's main objective is to determine the root causes of such limited levels of engagement, using fishbone diagrams (FBDs), fault tree analysis (FTA), and reliability block diagrams (RBDs) for data collection and analysis. Data was collected from a multidisciplinary cohort of mechanical, aerospace, and civil engineering students over a 5-year period. The top root causes were identified as "perception of engineering" and "nature of contents." The findings of this study were then used to create a revamped industry-inspired curriculum and multi-faceted assessment that is now currently deployed.

Keywords: engineering education, cross-disciplinary units, operations management, project management, computer simulation, hybridization

Introduction

Higher education institutions (HEIs) and professional accreditation organisations have devised several techniques to ensure that engineering students have all required but composite technical and managerial abilities to satisfy the continually changing demands of modern industry. Undergraduate engineering (UGE) students are ambivalent about interdisciplinary or cross-disciplinary units (Pulko and Parikh, 2003; Yunusa-Kaltungo et al., 2022; Yunusa-Kaltungo and Jungudo, 2022). Interdisciplinary programmes at HEIs educate students skills and knowledge outside their core subjects. Interdisciplinary units can teach students cognitive skills that are hard to learn in their technical subject. This research will focus on Operations Management course due its cohort size. Modern day business environments emphasise the importance of attracting graduate engineers with broad abilities, even though most HEIs can produce discipline-specific engineers. Nowadays, most employers prioritise graduate engineers with management qualities like teamwork, creative thinking, problem solving, and communication in addition to technical engineering knowledge (Iheukwumere-Esotu and Yunusa-Kaltungo, 2022; Hoddinott and Young, 2001; Iheukwumere-Esotu and Yunusa-

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Kaltungo, 2020; Ammar and Wright, 1999; Iheukwumere-Esotu and Yunusa-Kaltungo, 2021). Studies have indicated that cross-disciplinary units bore most undergraduate students (UGs) in general but may be more pronounced for technical programmes (Friedman et al., 2001). For instance, management and social science UGs miss class more than those in technical, mathematics, or laboratory-based courses, according to Friedman et al. (2001). Pulko and Parikh (2003) polled UGEs at five UK institutions and found that less than 10% of students think management units are valuable while close to 50% think the opposite. UGEs loathe such units even more. This disinterest also affects UGE class attendance. Pulko and Parikh (2003) argued that while female UGEs are more involved in management units than male UGEs, their opinions are typically eclipsed in high-level research findings due to their underrepresentation. Based on data acquired from one of the largest multidisciplinary UGE cohorts at the University of Manchester (i.e., Operations management (ENGM30461)), this study tries to understand the root causes of the poor student engagement levels. Fishbone diagrams (FBD), fault trees (FTs), and reliability block diagrams (RBDs) were used to collect and analyse the data, which also increased participation and response rates in this study. The students were asked to use the aforementioned root cause analysis tools to answer the following research question:

Why don't engineering undergraduates like management or cross-disciplinary units?

The remaining aspects of the paper are structured as follows: Section 2 discusses data collection for the case study. Section 3 covers FBD, FT, and RBD approaches. Section 4 proposes cross-disciplinary engineering module curriculum and assessment, while the final section concludes the study.

Data Collection Methodology

The case study

A study was undertaken to gain a deeper comprehension of the factors contributing to the lack of popularity of cross-disciplinary units among undergraduate engineering students (UGEs). Specifically, the study focused on the operations management unit (ENGM30461) offered to final year UGEs specialising in mechanical, aerospace, and civil engineering (MACE) at the University of Manchester (UoM). ENGM30461 represents a substantial cohort within the School of Engineering (SoE), boasting an average enrollment of around 350 students over the preceding five-year period. Given that ENGM30461 is a mandatory course for all students in the aforementioned programmes, the study population encompasses a wide range of perspectives from various disciplines.

The course ENGM30461 is a 10-credit course that requires 100 hours of active involvement. The 100-hour time allocation consists of many components, including weekly synchronous in-person lectures (22 hours), asynchronous tasks (5 hours), computer-based operations simulation laboratory tasks (9 hours), in-module MOCK evaluation (2 hours), end of unit revision (2 hours), and self-study (59 hours).

FBD, FT and RBD data collection instruments

The present study employed a total of five cohorts spanning the academic years from 2017/2018 to 2021/2022. Out of the total number of 1758 students that were extended invitations to partake in the data collection process, a response rate of 962 students was observed over the course of five years.

Every group gathered data over a period of 8 weeks. In the eighth week of Semester 1, the research question was frequently presented to the class following a lecture on operations management techniques for failure analysis and continuous improvement, specifically focusing on FBDs, FTs, and RBDs. In the present study, participants were given the opportunity to construct either representative FBDs or FTs depending on their subjective interpretation of the fundamental factors influencing the research question (RQ) outlined in Section 1. The primary focus of this study inquiry revolved around the examination of FBDs and FTs. The RBD serves to streamline the intricate branches of conventional FTs and FBDs. This methodology aids in the identification of robust, parallel-connected root causes RCs as well as susceptible, series-connected RCs. The exercise facilitated unrestricted participation by all FBDs and FTs, as it ensured anonymity and had minimal influence on unit grades.FBDs, FTs, and RBDs are frequently employed in the examination of process failures and accidents.

The visual representations effectively classify various system issues. These items possess exceptional visual quality, rendering them very suitable for the collection of instructional data. According to Shinde et al. (2018), the utilisation of these tools enhances the process of acquiring knowledge and fosters active engagement. Given the aforementioned premises, it can be concluded that the data collection strategy employed in this study was appropriate for the purpose of this investigation. This methodology facilitates the understanding of operational enhancement principles among undergraduate students and offers insights into their perspectives on cross-disciplinary units. The polling of MACE UGE students' opinions has been hindered by the issue of low response rates (Porter and Umbach, 2006).

Discussion of Results and their Implications

Out of the total of 1792 undergraduate students enrolled in this particular academic unit, 962 individuals successfully completed the exercise as part of the five-year research period. Out of the total sample size of 962 participants, 65% reported utilising FBDs, whereas the remaining 35% indicated using FTs. However, FBDs and FTs have the potential to incorporate the underlying reasons of behaviour when addressing the same research question, despite their differing approaches. The integrated FBD and FT depicted in Figures 1 and 2 were constructed by incorporating all of the identified root causes RCs, as it was unfeasible to present each individual student's FBDs and FTs. This review presents a compilation of the significant highlights from the major RC experiences of each student. In order to categorise their RCs, students are required to allocate them into five distinct primary groupings, denoted as M1-M5. Given that the majority of operations processes encompass the five fundamental elements, namely labour, materials, machines, methods, and money, the data collection endeavour employed these identical categories.

Figure 4 presents a ranking of the RCs based on their appearance and response volume, with the aim of identifying significant contributors. The seven groups of root causes (RCGs) presented in Table 1 and Figure 4 were derived by consolidating similar RCs identified in the unified FBD depicted in

Figure 1 and the FT illustrated in Figure 2. The diminished interest among UGEs in operations management as a cross-disciplinary field can mostly be attributed to their perception and content related factors. Examples of free text comments include:

• I fail to discern the connection between this particular unit, and the field of engineering (RC4).

• The field of engineering is distinct from the field of management (RC18).

• I fail to perceive the potential benefits that the knowledge from this course can offer me in an engineering role (RC24)

• The comprehension of practical engineering activities does not necessitate the implementation of operations management (RC25).

• The implementation of this unit ought to be limited exclusively to educational institutions specialising in business studies, as indicated by the designation (RC26).

• Excessive presence of management philosophies in the delivered contents (RC9).

• There is a perceived deficiency in the practical aspects of the unit, as it is mostly focused on theoretical concepts without including hands-on elements such as experiments or computer based laboratories (RC12)

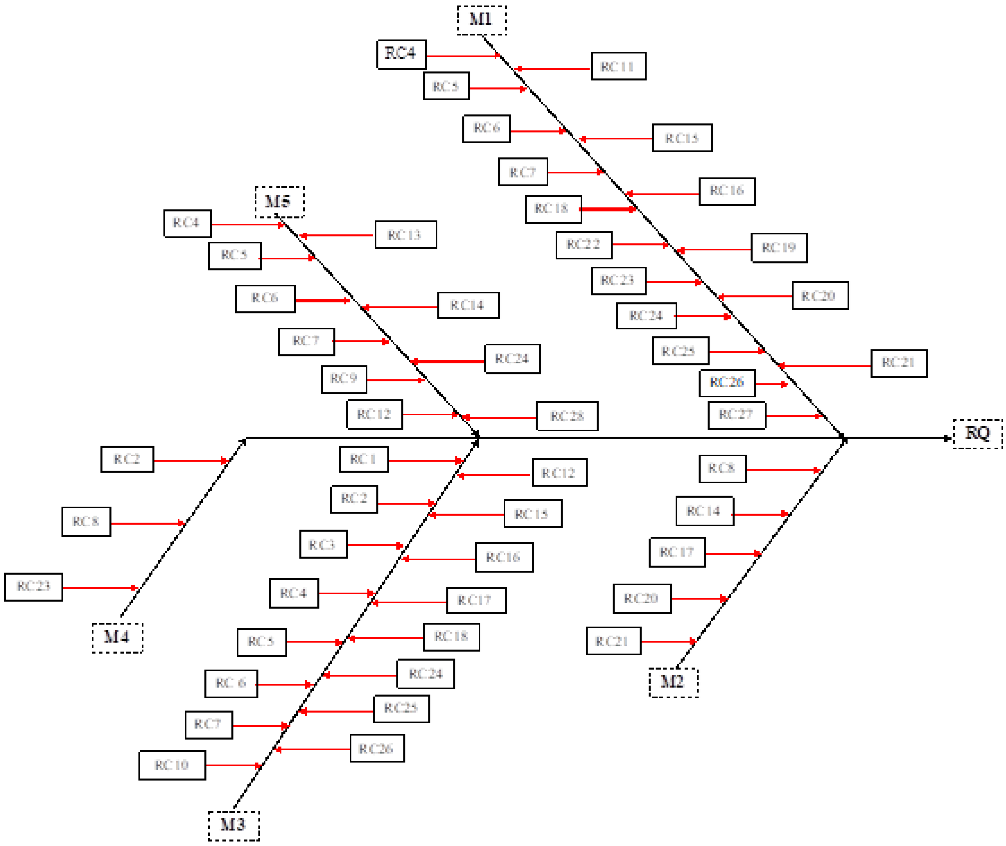

Figure 1: Unified FBD showing RCs related to the RQ

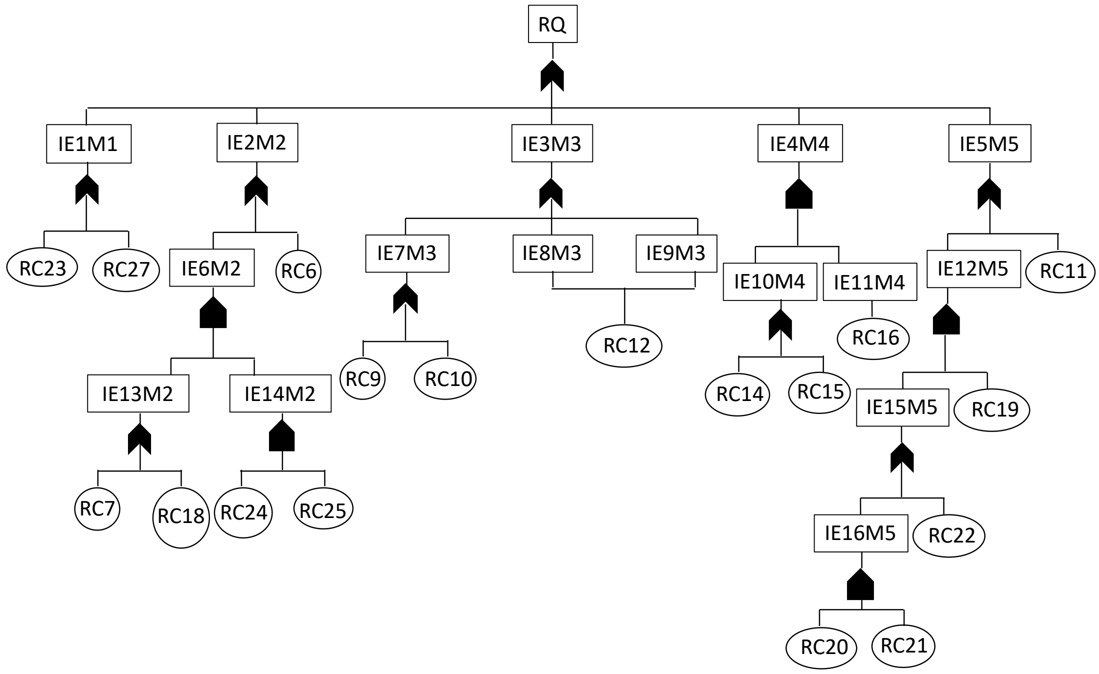

Figure 2: Unified FT showing RCs related to the RQ

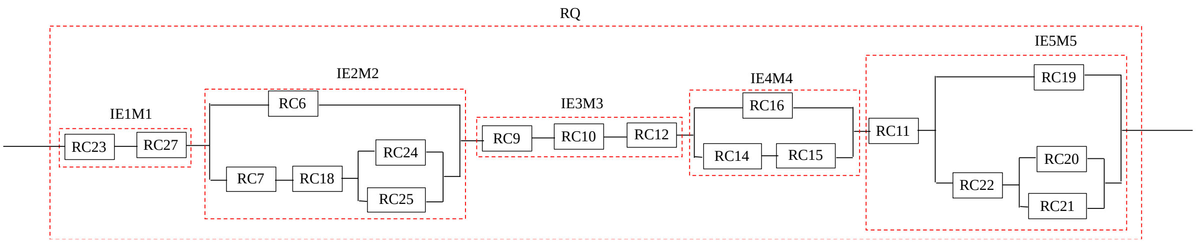

Figure 3: Equivalent RBD showing vulnerability and resilience point

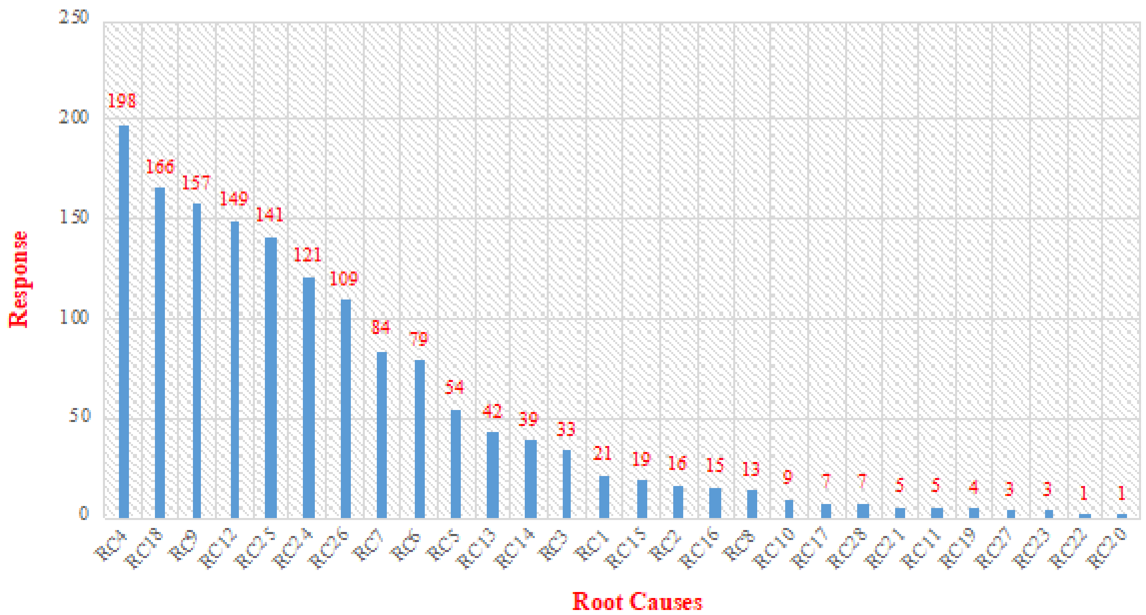

Figure 4: Distribution of RCs according to their frequency of appearance

Table 1: RCGs, their corresponding RCs and frequency of appearance

RCGs	RCG Code	Corresponding RCs	Frequency
Perception of engineering	RCG1	RC4, RC5, RC6, RC7, RC18, RC24, RC25, RC26	952
Nature of content	RCG2	RC9, RC10, RC12, RC13, RC28	364
Convenience	RCG3	RC1, RC2, RC, RC8	83
No penalty for missed attendance	RCG4	RC14, RC15, RC16, RC17	80
Lecturer	RCG5	RC11, RC19, RC20, RC21	15
Class size & nervousness	RCG6	RC23, RC27	6
Personal conflict	RCG7	RC22	1

The findings from RCG1 and its associated RCs indicate that a majority of undergraduate students in the field of engineering maintain the belief that engineering programmes should primarily focus on technical aspects. The impact of these narratives on the field of engineering has long been a subject of discussion. In Pearson's (2008) study titled "Changing the Conversation," the objective of the National Academy of Engineering was to alter the public perception of engineering. The report aimed to shift the prevailing perception of engineering as a field characterised by intricate complexity and mathematical challenges towards one that emphasises its potential for enhancing societal well-being and generating positive social outcomes. The survey moreover discovered that the majority of outreach communications conveyed by professional engineers and faculty members underscore the correlation between engineering and distinct attributes, primarily centred around mathematics and scientific aptitude. According to Pearson (2008), the field of engineering literature tends to overlook the importance of management skills such as teamwork, planning, and creativity. In a study conducted by Pawley (2009), a total of 10 faculty members from higher education institutions (HEIs) were questioned. The purpose of the study was to explore and analyse narratives related to engineering. As a result, three distinct engineering narratives were identified. The initial narrative establishes a connection between the field of engineering and the practical application of scientific principles and mathematical concepts. The second story establishes a connection between engineering and the process of problem-solving, while the third narrative establishes a connection between engineering and the creation of intricate technological advancements. A decade following Pawley's (2009) work, it is evident that narratives continue to prioritise STEM fields and technical expertise, while neglecting to acknowledge the importance of general and administrative skills.

Recommendations for Improvement

In order to develop a comprehensive student engagement strategy, it is imperative to take into account the three fundamental components of undergraduate education programmes: content, teaching methods, and assessment practises. The curricular pillar is required to clearly define and validate knowledge that adheres to established industry standards. In order to assure the achievement of desired learning outcomes, the teaching pillar places emphasis on the effective delivery of the curriculum. The ultimate component, assessment, evaluates the extent to which students remain engaged in their studies. Therefore, these suggestions will prioritise the qualities of resilience and long-term viability.

STEM and industry-inspired curriculum for cross-disciplinary units

UGE educators struggle to balance compelling topics with high academic requirements when designing curricula or unit materials. These tools must also prepare engineering students for industry challenges. Successful UGE programmes combine STEM and cross-disciplinary expertise. ENGM30461 achieved course goals using several sources. Industrial engineers and UGE programme accreditors are examples. Table 2 provides ENGM30461's delivery weeks and teaching blocks. Weeks 6, 7, 11, and 12 cover technical topics, while Weeks 2, 3, 4, 5, 8, and 10 cover cross disciplinary topics. Week 4 addresses operational processes in manufacturing organisations, where FBDs, FTs, and RBDs are developed using real-life case studies from industry engineers. Week 9 covers a comparable method in an intangible output or service provider like maintenance consulting. Most technical UGE units follow gamification and industrial engineering trends throughout development and deployment. Such teaching methods boost student involvement. For instance, utilising CAD platforms to teach mechanical and structural component design, 3D printing to make intricate parts for mechanical units, and SimuLink-based robotic control systems for aerospace and electrical engineering units have all increased student engagement. Similarly, welding, milling, lathe turning, and benchwork are being simulated with immersive technology. These challenges match the architecture of most video games modern students play outside of classroom (Ku and Fulcher, 2012).

Cross-disciplinary classes like ENGM30461 could incorporate a comparable gamification experience to enable students adapt "digital twin and industry 4.0" principles (with a concentration on discrete events simulation) to operations management.

Table 2: Recommended STEM and industry-inspired delivery framework for ENGM30461

Week	Teaching Block	Topic	ILOs
1	1	Introduction to operations management	ELS2, ELS7, P1
2		People and operations	DE6
3		Communications in operations management	DE6
4		Strategy in operations management	ELS2, ELS7, P1, P7
		Industrial interaction 1 (Oil & Gas Process)	ELS2, ELS7, P7, DE6
		Block one summative assessment	-------
5	2	Design thinking and innovation	DE8, ELS2, ELS7, P1
6		Process thinking and operations performance	ELS2, ELS7, P1, P7, P8
7		Industrial simulation digital laboratory (PLM Tecnomatix)	EP7, P1, P7, P8
8		Supply chain management	DE8, P1, P7, P8
9		Industrial interaction 2 (Maintenance consultants)	DE8, ELS2, ELS7, ELS2, ELS7, P7

		Block two summative assessment	-------
10	3	Intellectual property and licensing	ELS5
11		Continuous improvement in operations	ELS7, ELS2, P1, P7
12		Revision	-------
		IMPACT model support session and submission	-------
		Final assessment	-------

The certifying organisations' thorough explanations of Table 2's Intended Learning Outcomes (ILOs) are below: communication of a design to technical and non-technical audiences (DE6); ability to generate innovative designs for products, systems, components, or processes to meet new needs (DE8); knowledge and understanding of the commercial, economic, and social context of engineering processes (ELS2); awareness of relevant legal requirements governing engineering activities (ELS5); understanding of the key drivers for business success. Engineering entails communicating design concepts to technical and non-technical audiences (DE6); show they can design innovative products, systems, components, and procedures to address emerging needs (DE8); understand the commercial, economic, and social context of engineering processes (ELS2); knowledge of engineering laws (ELS5); understand innovation and growth drivers (ELS7); recognising versatility in operational settings (P1); improve efficiency by adjusting designs to operational needs; good understanding of the fundamental elements of quality and improvement (P7); as well as understanding how to use technical tools to handle technological uncertainties and risks (P8) in engineering operations so as to make informed decisions.

Multi-faceted assessment framework for cross-disciplinary units

One of the results derived from the FBDs and FTs is the impact that class sizes (RCG6) have on the level of involvement and participation exhibited by students in the various activities of the cross disciplinary unit under investigation. While the majority of students who emphasised the RCs associated with this RCG expressed concerns about the potential anxiety that may arise from the presence of large cohorts in cross-disciplinary units that could hinder students' levels of satisfaction and involvement. Cross-disciplinary units, as the name suggests, are courses that are offered to a diverse variety of academic programmes. Consequently, the class sizes for these units tend to be bigger compared to the average core technical lectures. In addition, the assessment methods employed by educators often consist of conventional essay-type questions that require manual grading. This poses a significant challenge for educators in terms of delivering comprehensive and uniform feedback to all students within the constraints of the allotted time.

To address this difficulty, this article proposes an alternative to the prevailing assessment methods that primarily rely on single-stage, essay-based evaluations with significant weighting. The suggested hybrid method is expected to enhance student involvement through the implementation of the continuous assessment component (Yunusa-Kaltungo et al., 2023). The hybrid approach yields four primary divisions, namely: light weight collaborative (LWC), MOCK zero weight independent (MZWI), heavy weight independent (HWI), and short zero weight independent (SZWI) assessments. Lightweight and zero-weight exams are commonly employed to promote incremental and enduring student involvement in the course, as well as fostering interaction among their classmates. This educational approach enhances the acquisition of knowledge by encouraging the systematic exploration of intricate concepts. Table 3 presents a comprehensive overview of the four assessment components associated with the hybrid approach. This includes information regarding their respective weights, frequencies, and descriptions.

Table 3: Summary of proposed hybrid assessment approach for ENGM30461

Type	Frequency	Duration	Weight (%)	Assessment Description
SZWI	Weekly for 11 weeks	30 minutes per test	0	Multiple choice questions (MCQs)
MZWI	Once in Week12	2 hours	0	MCQs, case study, short answer tests (SATs)
LWC	Once in Week1	8 weeks	20	Group coursework, case study, essay test, simulations
HWI	Once, end of semester	2 hours	80	MCQs, case study, SATs

Conclusion

It is evident that the majority of higher education institutions (HEIs) possess the capability to cultivate engineers who possess specialised expertise relevant to the market. In contemporary times, various sectors have a pressing demand for individuals who possess a diverse range of skills and knowledge across multiple disciplines. Regrettably, empirical evidence indicates that undergraduate engineering students (UGEs) exhibit a lesser degree of engagement with cross-disciplinary units compared to their core technical units, irrespective of the level of complexity involved. This phenomenon has an impact on the academic performance of a group of students and their level of involvement in educational activities. The present study conducted a comprehensive analysis of the limited cross-disciplinary unit interaction observed among undergraduate education (UGE) students. The study furthermore explores the establishment of a compelling evaluation framework for a cross-disciplinary units delivered to a substantial undergraduate education (UGE) cohort. The objective of this research is to analyse the cross-disciplinary Operations Management course (ENGM30461) offered to senior engineering students. In the context of an interactive data collecting method, participants voluntarily and anonymously constructed fishbone diagrams (FBDs), failure trees (FTs), and reliability block diagrams (RBDs) as visual representations to depict the underlying causes (RCs) of the research inquiry. The research conducted over a period of five years resulted in improved response rates, increased comprehension, and ongoing improvement. The RCGs that were most frequently seen were "Perception of engineering (RCG1)" and "Nature of contents (RCG2)." Based on the findings of research conducted on a certain group of undergraduate students (UGEs), it has been observed that a significant proportion of these students consider units related to science, technology, engineering, and mathematics (STEM) to be very pertinent. Furthermore, engineering is predominantly perceived as a technical discipline within this context, as indicated by the responses obtained from the research participants. The management units allocated to undergraduate engineering courses (UGEs) have also faced criticism due to their perceived level of difficulty and perceived lack of relevance to current engineering practises. These underlying presumptions resulted in the development of a novel delivery framework that integrates contemporary operations management approaches and elucidates their interconnections with various technical disciplines. The suggested curriculum, evaluation, and organisation also support the implementation of a strong online and blended learning approach in order to enhance student participation and the unit's ability to withstand unforeseen disruptions to traditional classroom instruction. Despite understanding some of the prevalent root causes of poor engagement with cross-disciplinary units via this study, the use of a single case study (i.e., a single unit within University of Manchester’s School of Engineering) might be viewed as a limitation, since some of the issues raised might be unit, region and/or institution specific. It would therefore be useful to further test the generalisability of the findings reported here by replicating the approach within several institutions across different regions.

Declaration of Interest Statement

The authors declare that they have no conflict of interests.

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