# Updating mathematics education for engineers

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# Updating Mathematics Education for Engineers.

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## INTRODUCTION

Engineering industry has changed greatly over the last 50 years during which time there have been many technological developments in engineering, and a significant increase in the IT based tools used in industry. For analysis, CAE software, specialist programing environments for numerical analysis and powerful statistical packages have become the workhorses of engineers who, half a century ago would have used slide-rules and log tables.

The mathematics curriculum for Undergraduate Engineers has, however, changed little, so it is important to consider whether this curriculum is still relevant to engineering graduates and the industry that they hope to graduate into. In mathematics classes around the world it is common to hear students mumble under their breath, "when will I ever use this in real life?" while they copy down another complex problem in algebra.

The initial literature search suggested that the issue is much broader than defining an appropriate curriculum. Teaching methods have a huge influence on students' ability to relate mathematics within engineering and design modules. Also, entry levels of understanding have been the subject of much research.  Apart from an anticipated range in intellectual abilities, there is huge variety in the topics that have been covered, even within a given pre-university qualification.

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# 1 SCOPING

The importance of defining limitations to the study became clear at an early stage. The research phase would include interviews with various stakeholders and the findings of this phase would inform the design of two surveys of undergraduate students and of practising industrialists to acquire new data. Mind mapping techniques were used to plan the project and target objectives that would be both useful and achievable.

The project objectives reported in this paper were to:

- investigate if the mathematics taught throughout undergraduate engineering education, matches the mathematical skills and knowledge required by industry employers;
- consider the appropriateness of GCE A-Level mathematics qualifications as preparation for undergraduate engineering study;
- make recommendations for the future content and teaching methods for mathematics in undergraduate engineering education.

For reasons of space, this paper includes only a selection of the available results.

# 2 INFORMATION SEARCH

## 2.1 Teaching, Learning and Student Motivation.

The study of engineering science and mathematics at university has traditionally consisted of lengthy programmes. Traditionally, lectures were a one-directional presentation of material, during which student activity is primarily restricted to taking notes, although occasionally a student may ask the lecturer a question. Some have adopted innovations such as clickers or personal response systems as ways of increasing the level of student involvement. Lectures introduce a large audience to certain mathematical concepts and procedures and provide students with a familiarity with the topic.

Unfortunately, even the most skilled teacher is relatively ineffective using this passive teaching method alone, and consequently, lecture materials should be supplemented by small-group tutorials or by some form of hands-on activity, such as coursework assignments, workbooks, IT based exercises or group projects. Furthermore, today's students are usually provided with a significant Virtual Learning Environment (VLE).

Student engagement is an essential part of the learning process, and universities need to provide motivators beyond the awarding of marks [2]. The choice of an engineering degree implies that students are interested in the practical applications of mathematics; if they were simply interested in mathematics they might have chosen to do a degree in that subject. Savage et al. [3] support the need for real applications and suggest that the high workload of undergraduate of engineering students can lead to reduced interest unless their intrinsic motivation can be

maintained or developed in some way. Innovative teachers like Robinson [5] have demonstrated improved student engagement by building their syllabus around group projects that are closely related to the cohort's interests. Teaching mathematics to Sports Technology students was always a challenge, but concentrating on sports-applications such as modelling the velocity of a downhill skier or the effects of lift and drag on golf balls provided the necessary connection. As well as sparking genuine interest, these projects also encourage the development of other skills required by industry such as reporting, presentations and teamwork.

The power and availability of graphical and numerical analysis tools suggests there may soon be no option to perform calculations on paper, so more focus needs to be put on the use of technology in mathematics courses for engineers. There is evidence, however, that the use of calculators has become a substitute for mathematical thinking [6] and it appears that some students view computational aids as a way of bypassing the need for understanding [6]. Anecdotally, students are inherently poor at realising whether the answer a computer gives is sensible or realistic and they need to learn to have an appreciation of what the answer should be, so we must ensure that the habitual use of calculators does not replace or erode basic or fundamental mathematical skills.

## 2.2 Course Content and Competences.

The SEFI Mathematics working group [7] sets out, in detail, eight mathematical competences that need to be attained by students. They list: thinking mathematically; reasoning mathematically; posing and solving mathematical problems; mathematical modelling, representing mathematical entities; handling mathematical symbols; communicating in and with mathematics; using aid and tools. It is, however, important to have a clear understanding of the relationship between mathematical contents/topics and competencies in order to recognize the role contents play in competency-based curricula. The same document contains an exhaustive level-based curriculum for mathematics.

## 2.3 Pre-University Mathematics in the UK

Most engineering degree programmes in the UK specify entry requirements that include a secondary qualification in mathematics. For many, the predominant standard is the 'General Certificate of Education Advanced level' or 'A-level' for short. There is a view that many students struggle with the transition from A-levels to undergraduate study, and that there is a discrepancy between the end of A-level study, and the start of degree level study - sometimes leading to a significant skills and knowledge gap [4].

A levels were first introduced in the UK in 1951 although they have changed considerably since then. They gradually evolved from a two-year linear course with an exam at the end, into a fully modular course by the year 2000. This is a key area of concern for universities as it means that a cohort of students with exactly the same A-level grades may have a variety of mathematical knowledge because

students have opted for, or been required to take dissimilar modules. For example, some may have concentrated on mechanics while others majored on statistics. Consequently, only a small core of material can be assumed for all students, with inevitable repetitions for others. In particular, researchers[8] around 10 years ago, provided evidence that universities could not assume that entrants had the level of familiarity with concepts in basic mechanics that were taken for granted in the past, although not all degree courses were modified to take this into account.

In recent years, the UK Department for Education has initiated a number of key changes to secondary education qualifications, the most significant of which is seen the reversal of modular A-Level qualifications to make them 'linear'[9]. In theory this means that there should be more commonality in their future A-Levels maths knowledge, skills and abilities. Reformed A-Levels in Mathematics, Further Mathematics and Statistics came into effect for students starting their 2 year A-Level course in 2017 [10], which means the first students with these reformed A-Levels will start university in 2019. The number of students entering top UK universities with other qualifications such as the international Baccalaureate, Scottish Higher or vocational BTEC qualifications is relatively small but simply adds to the mix.

### 2.4 The use of mathematics by engineers in Industry.

It is generally assumed that the majority of undergraduate engineering students will wish to pursue a successful career in engineering or industry, and as such they will need to be equipped with the appropriate skills to do so. Conversations with employers suggest that most are looking for a balance of skills, and that it is more important for graduates to have a holistic awareness of mathematics, than knowledge of specific mathematical topics. They need an appreciation of approximate scales and orders of magnitude, engineering principles based on mathematical ideas, and the ability to perform mental calculations [11].

Industry seeks undergraduates with both sound scientific knowledge and the transferable skills to apply it in a practical environment. Universities have traditionally focused on the specific technical and scientific skills of engineering rather than their applications and the "soft skills" such as communication and teamwork that industry requires [4]. Through their extensive survey work, Goold and Devitt [12] found, while almost two thirds of engineers use high level curriculum mathematics in engineering practice, mathematical thinking has a greater relevance to engineers' work compared to curriculum mathematics. Furthermore, mathematics in engineering is becoming increasingly reliant on technology. Graduates will certainly need familiarity with the relevant IT tools, as well as the ability to interpret the results they produce.

### 3. SURVEY CONSTRUCTION

The survey designs were based on lessons learned within the information search phase and constructed around the following ideas. Many of the questions had deliberate similarity across the two surveys so direct comparisons could be made.

1. Local survey of undergraduate engineering students.
   a. Effectiveness of the present Teaching and Learning methods.
   b. Pre-course preparation for study.
   c. Perceived appropriateness of the syllabus.
2. Survey of practising engineers in industry.
   a. Mathematics content of engineering degrees.
   b. The use of mathematics in industry.

The surveys mainly comprised a set of qualitative questions using a 5 point Likert scale but also contained some free text questions and space for additional comments. The surveys were designed to be anonymous.

After obtaining ethical clearance, the two surveys, were built online and trialled using several independent and unconnected persons. Their comments provided useful feedback to improve the questions and about time taken to complete it. The surveys were distributed by a variety of means including the use of social media and followed up four weeks later with a reminder.

## 4. RESULTS

### 4.1 The Undergraduate survey.

Exactly 100 responses were received from students of various engineering degrees. 68% were male and 32% female which over-represents the female proportion of the actual cohort. 90% of respondents were domiciled in the UK. Almost 80% of the respondents were studying either Mechanical Engineering (47%) or Product Design Engineering (32%) with the remainder being distributed in small numbers across a number of other disciplines such as electronic and electrical engineering, manufacturing, systems and sports engineering.
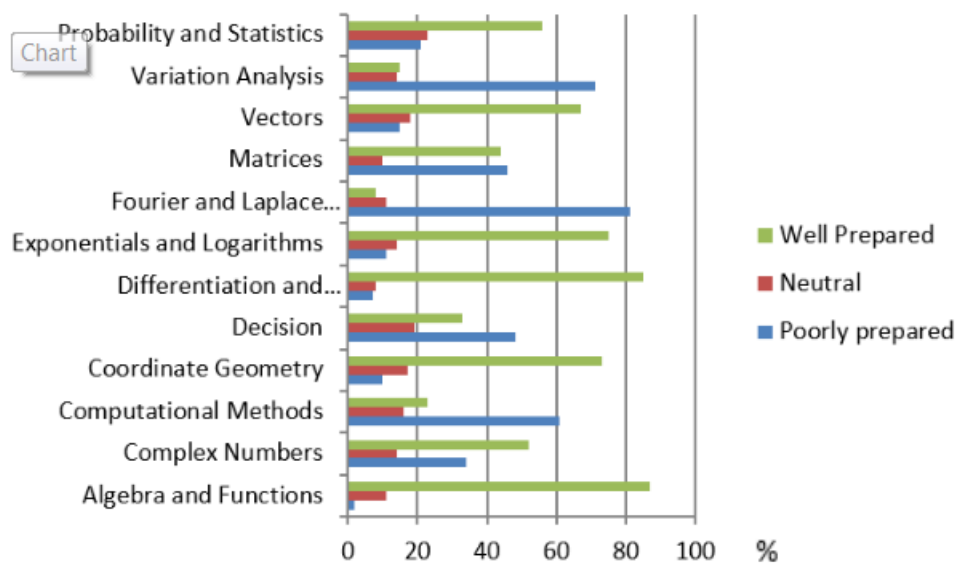


Fig. 1. Initial preparedness of students for studying key mathematics topics.

The respondents were quite evenly distributed across the four years of the degree and more than half already had at least 10 weeks of experience working in industry, mainly through longer placements or internships. 80% had entered the university with an A-level qualification in mathematics and several offered further mathematics as well. Reflecting on their pre-university studies, figure 1 shows a simplification of the Likert data received in which we have joined together 'well' and 'very well prepared' responses, similarly for the 'under-prepared', to which we have also added those who had not previously studied the topic at all. The main areas where prior knowledge appears lacking were variation analysis, computational methods and transforms. All are topics that few students have previously encountered.

Questioned about their career expectations, they predominantly believed in their need to understand fundamental mathematics but were less positive of their need for high level maths skills, 80% expected that they would be trained in specific mathematics as required. They certainly anticipated that they would be required to do mathematical analysis in their careers with only 7% to the contrary. Interestingly, they were aware of the importance of developing 'soft skills', with 82% rated these as more important than knowing many mathematics topics and only 1% less so, although many were neutral on this.

On a scale of 0 to 10, students were asked to compare the usefulness of theoretical and practical skills for their taught engineering modules and within their project work. On this scale, 0 represented purely theoretical, 5 represented equal usefulness and 10 was purely practical. On average, students scored 3.8 for usefulness in engineering modules and 6.5 for project work. Clearly, theory (such as mathematics) is thought to be more useful for taught university modules than in project work that more accurately simulates the industry environment.
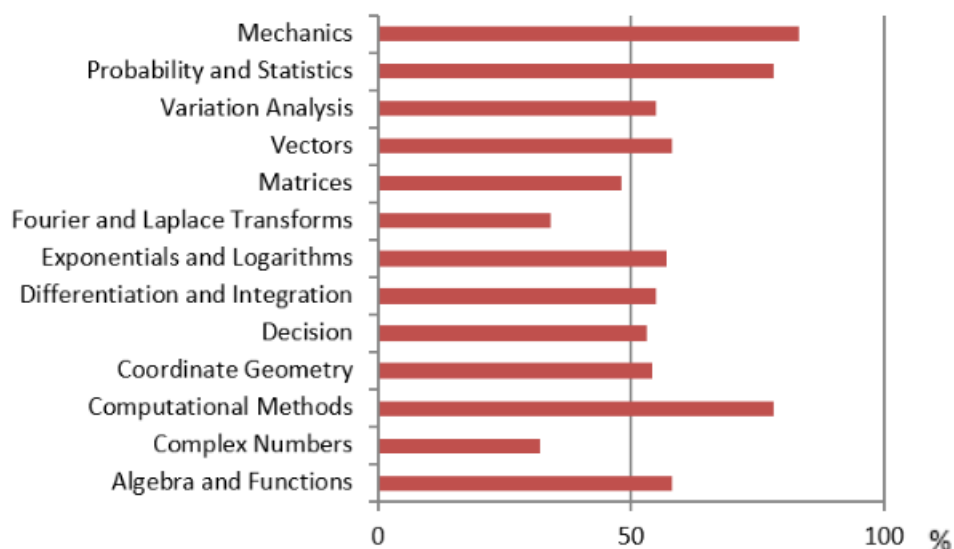


Fig.2,  I expect to use these maths topics in industry.

Half the respondents generally believe they have a good understanding of the mathematics that will be required of them in industry and it is interesting to note that this figure approximately coincides with the number that had spent time there, which begs the question about the many students who do not undertake placements etc. 65% of the sample also believed they were well prepared for industry. Figure 2 shows the students' expectations of how they will use their mathematics in their later engineering career. However, the placement students were asked how often they had actually used maths while in industry and the majority (54%) said less than once a month with only 9% needing maths every day.

Figure 3 shows the maths topics that students actually used while on placement which appears to support the need to shift towards computational tools. Students certainly expect to use the maths they had been taught. 95% agreed they would need to know the fundamentals, even though 10% expected to be working outside the engineering field upon graduation.
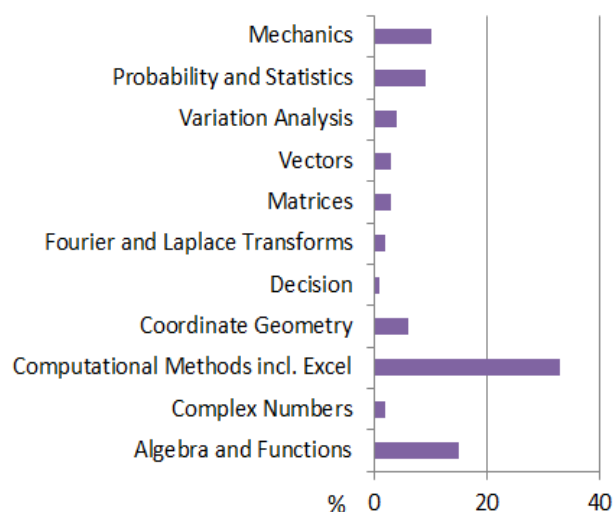


Fig. 3 Topics used on placement in industry.

The survey revealed the wide range of reactions to year-1 mathematics teaching. Quite a large proportion of this group had arrived with 'A' grades in maths and/or 'Further Maths'. As all the freshers are taught together, it is not surprising, and somewhat reassuring, therefore that many (51%) had found their maths easy in year-1. This, however, had a demoralising effect on the strong students. A number commented on this in their free text and some suggested teaching at different levels was needed. Around half (49%) agreed that their mathematics was taught well with another 24% neutral about this. 72% believed that the syllabi were appropriate for their engineering modules. They were quite emphatic that they learned more from tutorial sessions than lectures and also gained from feedback given after tests etc.

**4.2 The Industry survey.**

The authors were delighted to receive 78 completed responses of which 87% were

male and 13% female. 13% had influence or are responsible for the recruitment of graduates and 12% held managerial positions.

When asked about their experience of working with new graduates, 80% confirmed they arrived with adequate mathematical knowledge and few thought there was a need for further training in maths. Virtually all accepted that engineering graduates are expected to know a range of fundamental topics and 70% expected high level mathematical skills because, they claim, "graduates often do mathematical analysis". Emphatically, 90% thought graduates must be able to interpret the results of computational analyses with only 3% not needing this.

Company engineers were asked about the use of computational software by ranking on a scale of 0-10 where 0 represented hand calculations only, 5 represents equal usage and 10 represented only using computational software. The average score here was 6.2 showing a leaning towards the use of software. Using a similar scale, respondents were asked to rate the relative usefulness of theoretical and practical skills within the industrial environment. For this question, 0 represented purely theoretical, 5 showed equal usefulness and 10 was purely practical. On average, industrialists scored 5.7 reinforcing the predominant need for practical applications skills.

The industrialists reported a different view about how often mathematics is used. While 54% of placement students had stated their usage was very low at less than once a month, 46% of the responding industrialists used maths every week and only 20% hardly used maths.
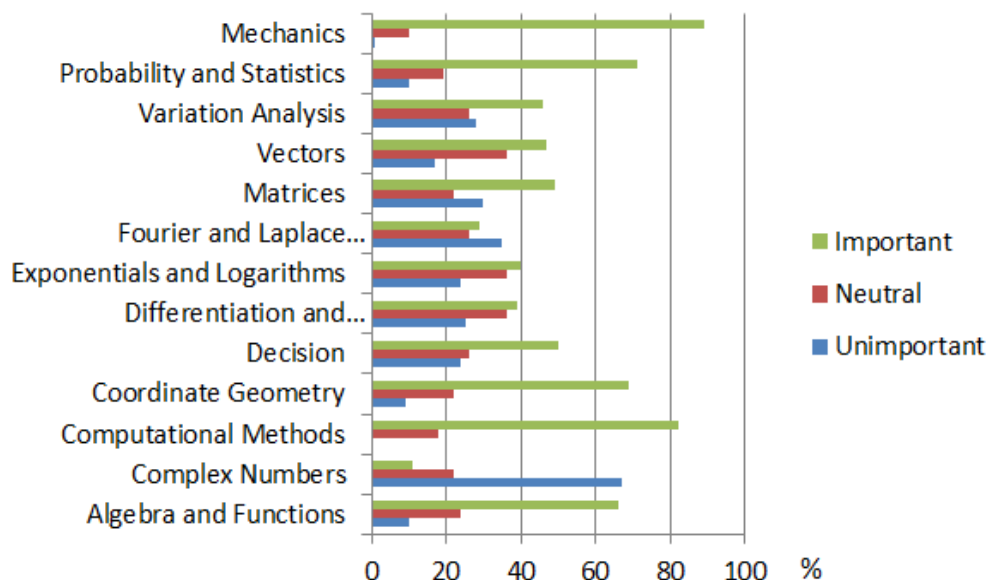


Fig. 4. Perceived importance of mathematical topics for industry.

Industrialists were asked to rate the importance of various maths topics, clearly this is very job dependent but the results, displayed in figure 4 confirm the importance of

fundamental topics such as algebra, geometry and mechanics and the need for familiarity with computational methods. They also reveal that more specialised treatments like transforms and complex numbers have a much lower priority.

The survey also asked if any topics were found lacking. Although this free text question was completed by many, the results were scattered.

Questioned about their experiences of working with new graduates, most found them to be enthusiastic (91%) and generally well prepared (63%), with a good understanding of the maths they need (68%). Around half the respondents had left university within the last 10 years and these people overwhelmingly believed that the mathematics they were taught had been relevant (84%). Despite many anecdotal reports to the contrary, only 27% were critical of graduates' lacking of 'soft' skills.

A number of respondents added comments about how maths education could be improved. A few examples are given here.

*"Teach where the maths is used….make (it) more engineering-focused with real world applications, not just theoretical basis….. Associate the mathematics to it's application";*

*"Subjects such as statistics, computational analysis and programming are becoming ever more important for engineers";*

 *"The course I attended did not cover probability in any great detail which would have been of benefit.";*

*"What is taught sometimes is out of sync on what the industry is using now. Be it older software/methodology or not used in real world application." ."a much deeper focus should be developed on computational methods in later years"." …..more emphasis on graphical mathematical methods".*

## 5  CONCLUSIONS

Both surveys provoked an excellent response rate. Despite this, the data has to be read in the context that the students were drawn from a single School in a single HE institution where the overwhelming majority were studying mechanical engineering. Furthermore, although it was intended to gather data from a wide spectrum of industrialists, the outcome defied this and was heavily skewed towards the aerospace industry so one might expect a higher than average need for high-level mathematical analysis.

This student sample felt generally well prepared for their mathematics studies at university and there is less of a mismatch than originally anticipated between the mathematics taught and the mathematical skills and knowledge required by industry. However, there is an appreciation that more focus needs to be put on statistics, variation analysis and computational methods within engineering education.

There is certainly work to be done regarding the effectiveness of the teaching methods for mathematics currently in use and, this work has specifically highlighted the need to tackle the wide range of entry-level abilities and competencies. Even though the majority of respondents had arrived with high grades from their secondary education, there was a wide range of abilities in the different sub-disciplines. Universities must, therefore teach an inclusive study programme. The danger of this is that topics that are well understood tend to appear easy and cause some students to lose interest. A flexible curriculum is needed to better accommodate the varied needs of a group of students.

Students clearly expect to make use of their mathematics, not just in applied modules at university but throughout their career. By some margin, they perceive the three most important topics as mechanics, statistics and computational methods and these choices were directly confirmed by the industrialists. Interestingly though, few had actually used mathematics other than computational methods while on placement.

Both surveys had few complaints about the teaching methods used or what they were being taught. However, the most commonly recurring theme concerned the need to demonstrate where and how the maths is applied with real examples.

The employers appeared quite satisfied that the graduates they receive were mathematically fluent but emphasised the need for general fundamental understanding of basic mathematics plus a strong appreciation of statistical, graphical and computational methods.

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