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# MATHEMATICS BACKGROUND OF ENGINEERING STUDENTS IN NORTHERN IRELAND AND FINLAND

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## **ABSTRACT**

The Organisation for Economic Co-operation and Development investigated numeracy proficiency among adults of working age in 23 countries across the world. Finland had the highest mean numeracy proficiency for people in the 16 – 24 age group while Northern Ireland's score was below the mean for all the countries. An international collaboration has been undertaken to investigate the prevalence of mathematics within the secondary education systems in Northern Ireland and Finland, to highlight particular issues associated with transition into university and consider whether aspects of the Finnish experience are applicable elsewhere. In both Northern Ireland and Finland, at age 16, about half of school students continue into upper secondary level following their compulsory education. The upper secondary curriculum in Northern Ireland involves a focus on three subjects while Finnish students study a very wide range of subjects with about two-thirds of the courses being compulsory. The number of compulsory courses in maths is proportionally large; this means that all upper secondary pupils in Finland (about 55% of the population) follow a curriculum which has a formal maths content of 8%, at the very minimum. In contrast, recent data have indicated that only about 13% of Northern Ireland school leavers studied mathematics in upper secondary school. The compulsory courses of the advanced maths syllabus in Finland are largely composed of pure maths with a small amount of statistics but no mechanics. They lack some topics (for example, in advanced calculus and numerical methods for integration) which are core in Northern Ireland. This is not surprising given the much broader curriculum within upper secondary education in Finland. In both countries, there is a wide variation in the mathematical skills of school leavers. However, given the prevalence of maths within upper secondary education in Finland, it is to be expected that young adults in that country demonstrate high numeracy proficiency.

## **KEYWORDS**

mathematics, numeracy, secondary school curriculum, CDIO standards 3, 7, 8

## **INTRODUCTION**

The School of Mechanical and Aerospace Engineering at Queen's University Belfast became a collaborator in the CDIO initiative in 2003. In the last eight years, much work has focused on the teaching of engineering mathematics within the School (Cole, 2011; McCartan et al.,

2011). In a CDIO teaching environment, a key consideration was to ensure that the engineering mathematics modules could integrate with all the relevant programmes and espouse the same active and interactive learning strategies inherent in other more design-orientated modules (conforming to CDIO Standards 3, 7 and 8). In more recent years, studies within the School have focused on a better understanding of students' skills on entry to their programmes (Cole & McCartan, 2013; Goodhew et al., 2013), and, in particular, have sought to identify specific issues in secondary-level education affecting the transition to engineering programmes in higher education. This paper involves an international collaboration on such a study.

The Organisation for Economic Co-operation and Development (OECD) claims that its mission is "to promote policies that will improve the economic and social well-being of people around the world" (OECD). It collects and analyses data from various countries on a wide range of topics including trade, industry, tax and lifestyle. A major focus is on education and skills. For example, OECD is responsible for the Programme for International Student Assessment (PISA), an international survey that evaluates education systems by testing 15-year-olds. It was the OECD Skills Outlook 2013 report, a survey of adult skills, however, which has provided impetus for this paper.

The OECD Skills Outlook 2013 report (OECD, 2013) investigated numeracy proficiency among adults of working age (16 – 65 years old) in 23 countries across the world. The findings made unpleasant reading for those in Northern Ireland where the mean score for numeracy proficiency fell below the mean score over all the countries and was ranked 17<sup>th</sup>. When the data for people aged 16 – 24 was examined, a similarly poor position for Northern Ireland was evident while Finland had the highest mean numeracy proficiency for this age group.

The report defines numeracy as "the ability to access, use, interpret and communicate mathematical information and ideas in order to engage in and manage the mathematical demands of a range of situations in adult life". It describes six levels of proficiency from "below level 1", which involves simple counting or basic arithmetic operations, to "level 5", which requires understanding of more complex and formal mathematical and statistical ideas. The percentage of adults in Northern Ireland performing at levels 4 and 5 was 8.5% while the mean value across all 23 countries was 12.2%. Finland had the highest percentage of adults (19.4%) performing at these levels of numeracy.

The sampling frames for the survey included population registers and address databases and therefore it is expected that people having a wide range of mathematics backgrounds were included. For those working in higher education or the engineering industry, however, it is a matter of concern whether the numeracy proficiency of engineering students and graduates in Northern Ireland similarly lags behind that of other populations.

To explore this question, a collaborative study across two universities in Northern Ireland and Finland has been performed. This investigates the prevalence of maths within the secondary education systems in the two countries and reports the mathematical competency of students entering higher education and particular issues associated with transition into university. The paper aims to identify reasons for the contrasting numeracy proficiencies of people aged 16 – 24 in the two countries. This is timely given the ongoing discussion in the UK regarding the structure of the upper secondary maths curriculum.

## EDUCATION SYSTEM IN NORTHERN IRELAND

Table 1 outlines the education system in Northern Ireland. There are 12 years of compulsory education with children starting primary school at age four. The government Department of Education specifies that the primary curriculum must include language and literacy, mathematics, the arts, the world around us, personal development, physical education and religious education (DENI 1). After seven years at primary school, pupils move to secondary education at age 11. About 58% of pupils attend secondary schools and 42% attend grammar schools (DENI 2). Entrance to grammar schools typically requires pupils to pass an entrance exam based on mathematics and English. The secondary curriculum involves a broad range of subjects including English language and literacy, mathematics, modern languages, art, music, geography, history, science and technology, physical education and religious education (DENI 1). There is some flexibility in the final two years of compulsory secondary education when students study for the General Certificate of Secondary Education (GCSE) exams. Typically, they select nine or ten GCSE subjects with mathematics, English and science being mandatory.

Table 1. Education System in Northern Ireland

Age			Duration in years
	Doctoral degrees: universities		
	Master's degrees: universities		1-2
19-22	Bachelor's degrees: universities		3-4
17-18	Secondary education (advanced level): grammar/secondary schools	Further education, vocational qualifications: regional colleges	2
11-16	Secondary education: grammar schools	Secondary education: secondary schools	5
4-11	Primary education		7

### Upper Secondary Education

After this compulsory schooling, about half of the students continue with two more years of secondary education. This is the A-level (or Advanced level) stage where students normally focus on just three subjects. An AS-level is the first half of an A-level and can be taken as a separate qualification. Thus, while studying for three A-levels is the norm, many students take the opportunity to do an AS-level in a fourth subject. A-level results are used to determine the suitability of students for higher education. For example, Queen's University Belfast selects students prior to enrolment on their degree programme by considering their A-level grades against published thresholds with typically a minimum of grade B required in Mathematics for a student desiring to study mechanical or aerospace engineering.

In the UK, five organisations, known as examination boards, provide A-level curricula, exams and assessment. Schools are free to register with whichever exam board they believe is most suitable to their needs. A-levels were reformed in 2000 with a modular structure introduced. A-level mathematics was further reformed in 2004 in an attempt to encourage more students to study this subject (Porkess, 2003; QCA, 2007).

The exam board based in Northern Ireland provides an A-level Mathematics curriculum (CCEA, 2010) which involves four core modules of pure maths (C1 – C4) plus a selection of two out of four optional modules of applied maths (M1, M2, S1, S2). The module content is summarised below:

**C1** (pure): indices, quadratic equations, polynomials, graphs of functions, straight line, differentiation.

**C2** (pure): circle geometry, sequences, series, binomial expansion, solving triangles, trigonometry, logs, integration for area.

**C3** (pure): partial fractions, parametric equations, exponential function, further differentiation (product, quotient, chain rules), solving equations by iterative methods, numerical integration.

**C4** (pure): functions, differential equations, volume of revolution, implicit and parametric differentiation, integration by substitution and parts, vectors (algebra, geometry, scalar product).

**M1** (mechanics): uniform acceleration, force vector, friction, equilibrium, Newton's laws of motion, impulse, momentum.

**M2** (mechanics): integration and differentiation of vectors, projectiles, circular motion, potential and kinetic energy, work-energy principle, power.

**S1** (statistics): presentation of data, summary measures, probability laws and functions, discrete and continuous probability distributions, normal distribution.

**S2** (statistics): expectation algebra, random sampling, central limit theorem, confidence intervals, hypothesis testing, bivariate distributions, linear regression.

A separate A-level qualification in Further Mathematics involves an additional six modules, three of which are pure maths while the other three involve some combination of mechanics and statistics modules depending on which of these have already been taken for A-level Mathematics. Topics in further pure maths include matrices, determinants, groups, complex numbers, proof by induction and hyperbolic functions. Further mechanics topics include centre of mass, relative velocity, simple harmonic motion, satellite motion and Newton's law of restitution.

The number of Northern Ireland students studying A-level Mathematics has risen steadily over the last nine years from 2250 in 2005 to 3176 in 2013 (JCQ, 2013). This latter figure is estimated to represent about 25% of A-level students in Northern Ireland (Department of Education, personal communication). A-level Further Mathematics tends to be taken by only a small proportion of students, about 5% of the number taking A-level Mathematics in recent years (JCQ, 2013).

About 36% of Northern Ireland school leavers gained at least three A-levels at grades A\* – C (the higher grades suggesting capability of progressing to university) in 2011/12 (DENI 3). It is estimated that about 12% of Northern Ireland school leavers in 2011/12 achieved A-level Mathematics at grades A\* – C standard.

While successful completion of A-level study is the normal route to university, there are alternatives. Over the five-year period until 2011/12, 42% of Northern Ireland school leavers went directly into higher education, 32% continued into further education and 13% entered training (DENI 3).

## **Further Education**

A different government department, the Department for Employment and Learning, is responsible for further education in Northern Ireland. Six regional colleges provide a wide range of vocational and academic programmes (DEL) including Extended Diplomas (two-year vocational course), Higher National Diplomas (two-year course, combination of work experience, practical experience and academic study) and foundation degrees (two-year course, combination of university study and work experience) (ANIC). Entry requirements depend on the course but often involve prior educational achievement. Successful completion of these courses can permit progress to university degree study.

Even within an engineering programme, maths does not feature prominently. For example, the BTEC Extended Diploma in Engineering involves six mandatory units worth 70 credits (including a 10-credit unit in maths) plus a selection of about 11 optional units which will include at most another 10-credit unit in maths (Pearson, 2013). This qualification has a strong vocational emphasis but is said to be broadly equivalent to three A-levels and allows progress towards beginning a university degree programme (Pearson, 2013). The topics in the mandatory maths unit are: indices and logarithms, linear and quadratic equations, circular measure, trigonometric function graphs, surface areas and volumes of regular solids (cylinder, sphere, cone), statistical diagrams and measurement, elementary differentiation and integration. The topics in the optional maths unit include: graphical techniques for solving equations, arithmetic and geometric progression, complex numbers, trigonometrical graphs and formulae, rules for differentiation, turning points, numerical integration.

## **Higher Education Teaching Experience**

In Queen's University Belfast, the syllabus in the introductory mathematics module for first-year aerospace and mechanical engineering students (class size is approximately 170) is mainly a repetition of A-level topics although effort has been made to demonstrate engineering applications. Teaching is made difficult due to the wide range in mathematical ability of the students. In each of the last four years, a small group (~5%) has benefitted through taking the more advanced A-level Further Mathematics at school but another small group (~5%) did not study A-level maths, following an alternative route to university. It was clear that this latter group found the module to be very challenging.

Even amongst the A-level maths students, there is a wide range of ability. For example, students with grade B in A-level maths have scored over a wide range (20% – 90%) in the introductory maths module at university, despite this module being largely a repeat of A-level material. Some students with good grades in A-level mathematics have not mastered certain integration techniques and there is sometimes confusion in taking a rule for differentiating (product rule) and applying it to an integration problem.

Another issue concerns A-level maths module choice. Given the various allowable combinations of modules within A-level maths, two students could have an A-level maths qualification, with the same grade, but have studied different topics. For students in the School of Mechanical and Aerospace Engineering at Queen's University Belfast, a combination of mechanics and statistics was strongly the most popular choice of optional modules in A-level maths, meaning that only about one quarter of the class had studied mechanics beyond the basic module within school maths (Cole & McCartan, 2013).

Experience suggests that, for most students, some revision of A-level material is necessary and beneficial within first year at university. At school, students were provided with formulas to be memorised and were shown how to do questions. At university, they appreciated gaining some extra background theory and examples of where the maths can be applied in engineering, believing this to be important for their learning. They believed that having the theory, seeing where formulas came from, and deriving results through a step-by-step method would aid their learning and understanding (Cole, 2011).

## EDUCATION SYSTEM IN FINLAND

The education system in Finland is shown in Table 2. Early childhood education takes place at kindergartens or smaller family-day-care groups. Almost all 6-year-olds participate in pre-primary education which is free and provided by municipalities. Children start nine years of compulsory education in the year when they turn seven. Instruction is usually given by the same class teacher in most subjects in the first six years and by subject specialists in the last three years. The national core curriculum for basic education is determined by the Finnish National Board of Education. It contains the objectives and core contents of different subjects, as well as the principles of pupil assessment (Ministry of Education and Culture, Finland et al., 2013).

After basic education, 95.5% of school-leavers continue immediately in additional voluntary basic education (2.5%), in upper secondary schools (54.5%) or in initial vocational education and training (38.5%). Students in upper secondary schools have the option of studying for both a vocational qualification and the matriculation examination at the same time (Ministry of Education and Culture 1).

Completion of upper secondary education, both general and vocational, gives students eligibility to continue to higher education towards bachelor's degrees at universities or polytechnics, also called universities of applied sciences.

Table 2. Education System in Finland

Age			Duration in years
	Doctoral degrees: universities Licentiate degrees: universities		
	Master's degrees: universities	Polytechnic master's degrees: polytechnics Work experience	2 3
19-22	Bachelor's degrees: universities	Polytechnic bachelor's degrees: polytechnics	3
16-19	Matriculation examination: general upper secondary schools	Vocational qualifications: vocational institutions	3
7-16	Basic education: comprehensive schools (+ voluntary additional year of basic education)		9
6	Primary education: kindergartens		1
0-5	Early childhood education and care: kindergartens or smaller family-day-care groups in private homes		5

## **General Upper Secondary Education**

After the compulsory comprehensive school, about half of the relevant age group continues their studies within general upper secondary education. Student selection to upper secondary schools is mainly based on the students' grades in their basic education certificate. Typically the general upper secondary education takes three years, but it can be accomplished in two to four years. The general secondary education ends with a national matriculation examination, which provides general eligibility for higher education (Ministry of Education and Culture).

The national core curriculum for upper secondary schools defines the core contents and objectives of the school work. The core curriculum was reformed in 2003 and the local curricula based on it have been applied since August 2005 by each education provider. The next reform in the core curriculum is expected to come into effect in 2016. Note that the legislation on the scope and structure of the studies is partly different for the general upper secondary education for young people and for adults who begin their studies after turning 18. In what follows, only the youth education (Finnish National Board of Education, general upper secondary education) will be discussed.

The upper secondary school curriculum is comprised of a vast range of subjects:

- mother tongue and literature (Finnish or Swedish)
- languages (including Swedish or Finnish)
- mathematics, basic or advanced syllabus
- environmental and natural sciences: biology, geography, physics and chemistry
- religion / ethics, philosophy, psychology, history, social studies
- arts and physical education, health education, and educational and vocational guidance

The government decides on the distribution of the lesson hours in different subjects and subject groups and for student counselling. The studies consist of compulsory, specialisation and applied courses. A course comprises of approximately thirty-eight 45-minute periods or equivalent. The number of compulsory courses varies from one to ten between different subjects. Specialisation courses relate to the compulsory courses in the same subject, and there can be both nationally determined and school-specific courses. To achieve the upper secondary school leaving certificate, each student must take a total of at least 75 courses. Of these, 47 to 51 are compulsory, depending on the choice of syllabus in mathematics. The minimum total of specialisation courses is ten (Eurypedia).

For the basic mathematics syllabus, there are six compulsory courses and two nationally defined specialisation courses while, for the advanced mathematics syllabus, there are ten compulsory courses and three nationally defined specialisation courses. The number of compulsory courses in mathematics is proportionally large: the only other subjects with six compulsory courses are mother tongue and literature, and the so-called A-language (the first foreign language).

According to the basic syllabus, the compulsory courses in mathematics are:

- Expressions and equations: graphical and algebraic solutions, solving quadratic equations.
- Geometry: right-angled triangle trigonometry, areas and volumes.



- Mathematical models: linear and exponential models, power equations, exponential equations, solving equations, linear programming, arithmetic and geometric progressions.
- Mathematical analysis: behaviour of polynomials, graphical and numerical methods.
- Statistics and probability: continuous and discrete distributions, normal distribution.

The specialisation courses are commercial mathematics (money transaction, loan and tax calculations, mathematical models applicable to economic situations, using number sequences and sums) and mathematical models (solving trigonometric equations, trigonometric graphs as modellers of periodic phenomena, basic vector calculations). The basic syllabus aims to develop skills in processing and understanding mathematical information and using mathematics in everyday life situations.

The advanced mathematics syllabus aims to develop the mathematical skills required in vocational and higher education and encourage use of mathematical language, analysis, modelling and problem solving. The compulsory courses in the advanced mathematics syllabus are:

- Functions and equations: power equations, exponential and polynomial functions.
- Geometry: sine and cosine rules, circle geometry, calculating areas and volumes, analytical geometry (distance of a point from a straight line).
- Vectors: addition, subtraction, scalar product, lines and planes in space.
- Probability and statistics: discrete and continuous probability distributions, expected values of discrete distributions, normal distribution.
- Calculus: derivative, product and quotient rule, extreme values of a polynomial function, integration of elementary functions, calculating areas and volumes.
- Radical and logarithmic functions: their derivatives and inverse functions.
- Trigonometric functions: their derivatives, solving trigonometric equations.
- Number sequences: arithmetic and geometric progressions and sums.

The specialisation courses are number theory and logic, numerical and algebraic methods and advanced differential and integral calculus. Most schools do offer at least one additional, school-specific mathematics course, namely the preparatory course for the matriculation exam. (Finnish National Board of Education, national core curriculum for general upper secondary education intended for young people 2003).

### ***Vocational Education and Training***

The Finnish National Board of Education decides on the national core curriculum for each vocational qualification, determining the composition of studies and objectives, core contents and assessment criteria for study modules. It also includes provisions on student assessment. The content of local curricula is also defined in the national core curricula. The Finnish National Board of Education has revised all national requirements of vocational qualifications which have been taken into use in August 2010. There are 52 upper secondary vocational qualifications including a total of 120 different study programmes. The revision includes the structure of the requirements, the organisation of studies, the skills requirements as well as the targets and criteria of assessment (Eurypedia).

Vocational education and training includes vocational studies (90 credits) in the field concerned, general studies (20 credits) supplementing vocational competence (mother

tongue, second national language, a foreign language, mathematics and science, humanities and social studies, health education, and art and craft subjects) and elective studies (10 credits). Here, one credit means 40 hours of study work. At different points during their training, students demonstrate the skills they have learned in tests arranged as either practical work situations or as practical assignments. These skills demonstrations assess how well the student has achieved the competencies needed in the labour market. The aims and assessment criteria of the skills demonstrations are determined in the core curricula issued by the National Board of Education. The tests are devised and implemented in cooperation with business and industry and other employers. Vocational education and training providers appoint special bodies to plan and set the tests and also appoint the examiners (Ministry of Education and Culture 2).

For example, the vocational qualification in Information and Telecommunications includes mathematics (3 credits) and mother tongue (4 credits). Targets of assessment in mathematics include basic calculations, percentage calculations, unit variations, problem solving and result assessment, using a calculator and computer, and processing and analysing numeric data (Finnish National Board of Education, 2009).

The entry requirement is a leaving certificate from the comprehensive school (basic education) or an equivalent amount of studies. Students usually apply to vocational education and training through a national joint application system. There are no tuition fees in initial vocational education and training. Students pay part of the costs, e.g. textbooks and personal tools, equipment and materials, which they keep after training. Meals are free. (Ministry of Education and Culture 2).

### **Higher Education**

The objectives, extent and overall structure of degrees in universities and polytechnics are defined by the Finnish government decrees. The universities decide on the detailed contents and structure of the degrees they award. They also decide on their curricula and forms of instruction. The Ministry of Education confirms the degree programmes of polytechnics, and the polytechnics decide on the content and structure of their degrees in more detail. The polytechnics also decide on their annual curricula and forms of instruction (Finnish National Board of Education, higher education).

Universities and polytechnics use different kinds of student selection criteria. Most commonly, these include success in matriculation examination and entrance tests. The general requirement for admission to polytechnics is completion of general upper secondary education or vocational education and training. Student selection to polytechnics is mainly based on entrance examinations, school achievement and work experience (Finnish National Board of Education, higher education).

For example, the national entrance tests for technology, communication and transport in polytechnics take place in June every year. The test includes two parts: reading comprehension (maximum 5 points) and ten exercises about mathematics, logical reasoning, physics and chemistry (maximum 30 points). The applicants also get points from work experience (maximum 5 points), success in school (55 points) and the first target of application (maximum 5 points). Although a minimum of ten points in the entrance test is required, the mathematics teachers of polytechnics are generally not very satisfied with the new students' mathematical skills (Ernvall & Ernvall, 2003; Korhonen, 2008; Tuohi et al., 2004; Tuohi, 2009). The majority of students who have chosen advanced syllabus in upper

secondary school continue their studies in universities other than universities of applied sciences (polytechnics). For example, in the degree programme in Information Technology at Turku University of Applied Sciences, only about one third of students have had this background in the last 15 years and many of them did not have high attainment in mathematics. The students who start to study technics with a basic syllabus background are often not very motivated to study technics, and this affects retention rates during the first year in polytechnics.

There is a large variation in mathematical skills amongst students enrolling in polytechnics, which can be attributed to their different educational backgrounds. The mathematics instruction in general upper secondary education is relatively uniform throughout the country and the mathematical skills of new students reflect their school marks. The difference between the mathematical skills of basic and advanced syllabus students, as observed in a study at Turku University of Applied Sciences, is very high and similar to the difference between the mathematical skills of vocational school and advanced syllabus students (Tuohi et al., 2004).

## CONCLUSIONS

In both Northern Ireland and Finland, about half of school students continue into upper secondary level following their compulsory education. This stage of education takes two years in Northern Ireland but Finnish pupils typically spend three years at upper secondary level. A major difference between the two countries concerns the upper secondary curriculum – Northern Ireland students focus on three subjects while Finnish students study a very wide range of subjects covering maths, science, language and arts, with about two-thirds of the courses being compulsory. The number of compulsory courses in maths is proportionally large, suggesting that maths is particularly valued in Finland. This means that all upper secondary pupils (about 55% of the population) follow a curriculum which has a formal maths content of 8%, at the very minimum – the content will be higher, maybe ~18%, for those who take the advanced syllabus with extra, specialisation courses. In contrast, only about 13% of Northern Ireland school leavers had studied A-level Mathematics (2011/12 figure).

The corresponding upper secondary syllabi are not very similar, however. The compulsory courses of the advanced syllabus in Finland are largely composed of pure maths with a small amount of statistics but no mechanics. While the majority of the pure topics which are core in Northern Ireland are included in the Finnish compulsory courses, some topics – including partial fractions, integration by parts, numerical integration, Newton-Raphson method, differential equations – are not. (With the exception of differential equations, these topics are included in the specialisation courses in Finland.) Given the much broader curriculum within upper secondary education in Finland, it is not surprising that the core topics within maths are not as extensive.

There is a wide variation in the mathematical skills of school leavers in Finland between those who followed the basic and advanced maths syllabus. Nevertheless, even the study of basic maths should provide valuable life skills through, for example, the course in commercial maths.

Maths is also emphasised, to a small degree, within vocational programmes in Finland; these contain a general element which includes maths. This is not the case for all vocational

qualifications in Northern Ireland – for programmes in, for example, travel and tourism or agriculture, there is a strong vocational focus.

Given the prevalence of maths within both upper secondary and vocational education in Finland, it is not surprising that young adults in that country demonstrate high numeracy proficiency.

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