DOCUMENT RESUME

ED 397 246 CE 072 048

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TITLE	Failures and Reform in Mathematics Education: The Case of Engineering. National Institute Briefing Note No. 5.
INSTITUTION	National Inst. of Economic and Social Research, London (England).
PUB DATE	94
NOTE	9p.
PUB TYPE	Reports - Research/Technical (143)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Academic Achievement; *Educational Change; *Engineering Education; Foreign Countries; Higher Education; *Mathematics Education; Standards; Vocational Education
IDENTIFIERS	Advanced Level Examination; *Great Britain

ABSTRACT

The structure of education for 16- to 18-year-olds in Great Britain discourages them from making mathematics, science, and engineering serious options for future study. The emerging structure of the labor market, in which a large proportion of high-status jobs do not require higher mathematics, increases the numbers who decide not to commit themselves to specific mathematics/science/engineering choices. Reforms that maximize rather than minimize the potential pool of engineering higher education entrants involve an examination of the level and consistency of mathematics provision within engineering and preengineering courses and a rethinking of the new General National Vocational Qualifications (GNVQs). A-level (advanced-level) mathematics poses problems for engineering recruitment because of the uniquely specialized nature of A-level choice and the perceived difficulty. If A levels remain unreformed, alternative ways of continuing mathematics learning beyond high school are needed. The most popular alternative to A levels in full-time study is one of the Business and Technology Education Council courses in which few students receive formal mathematics instruction. Current government policy envisions that GNVQs will become the major alternative to A levels. Unfortunately, GNVQs may lower the level of mathematics learned. Options for mathematics provision in postcompulsory education include the following: separate mathematics teaching in GNVQs, intermediate mathematics qualifications, A-level reform, and a change in higher education entry requirements. (YLB)

NATIONAL INSTITUTE OF ECONOMIC AND SOCIAL RESEARCH

FAILURES AND REFORM IN MATHEMATICS EDUCATION: THE CASE OF ENGINEERING

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National Institute Briefing Note no. 5

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Failures and reform in mathematics education: the case of engineering

A Briefing Note[1]

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The mathematics attainment of young people is of key importance to any modern industrial society, and quite especially to the future of engineering and engineering-based manufacturing. In England and Wales, however, while university arts and social science courses are swamped with applications, engineering (and science) faculties find themselves unable to fill the places available. Moreover, mathematics is decreasingly popular at A level. Many of the young people now starting engineering have limited mathematical skills, and, not surprisingly, find it very difficult to cope.

There is nothing very mysterious about this situation - nor about the remedies. Young people are generally rational, and respond to the structure of 16-18 education, and the opportunities of the current labour market. Unfortunately for this country, its educational structure positively discourages students from making maths, science and engineering serious options for future study. It also offers much of its supposed maths teaching for older students in a form which maximises paperwork and minimises learning. It is the irrationality of our current post-16 provision which is the problem.

This discussion note reviews current provision and explains why it is so inappropriate. It also offers remedies, all them straightforward and easy to implement. Change is certainly necessary. It may be tempting to argue that the growing productivity of manufacturing and engineering so reduces employment in these sectors that we need not be concerned - but this argument ignores the fundamentally quantitative and mathematics-based nature of modern societies. Managers and workers need mathematical and engineering "literacy" to operate effectively in exactly the same way as they need a command of language.

Research on career choice indicates that, reasonably enough, most young people at 16 want to keep their options open: to maximise their future choices and to "position"

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[1] An earlier version of this paper was prepared for use by the Engineering Council: but the views expressed here are entirely the author's own. It draws on research carried out over a number of years, and on experience in a university department concerned with the training of graduate mathematics teachers, and with in-service training of mathematics teachers in schools and further education. Of particular importance is a programme of comparative research on mathematics in European vocational education based at the National Institute of Economic and Social Research, in which the author collaborated. See A. Wolf, Mathematics for Vocational Students: Contrasting Provision and Consequences NIESR Discussion Paper 23, 1992. The views expressed here draw directly on this research: but also on a survey of post-16 mathematics syllabuses carried out for NCVQ (1991); a development project on mathematics and technology, carried out by the Institute of Education for the Employment Department (TVEI); research into the mathematics requirements of industry and commerce (funded by the Employment Department); and ongoing work for the Nuffield Foundation on mathematics for engineering technicians. See, for example, A. Wolf Practical Mathematics at Work (Sheffield: Employment Department 1986): A. Wolf. M. Kelson & R. Silver Learning in Context (Sheffield: Employment Department 1990); A Wolf "Testing Investigations" in P. Dowling & R. Noss eds Mathematics versus the National Curriculum (Falmer 1990); A Wolf & M-T Rapiau "The Academic Achievement of Craft Apprentices in France and England: contrasting systems and common dilemmas" (*Comparative Education* 29.1 1993).

themselves for maximum flexibility and opportunity in the labour market. While a few dedicated and able young people are always likely to be clear, at 16, about their career choice, most are not. At present, the structure of courses in England (and to a lesser degree Scotland) works to *minimise* the pool from which HE entries into engineering might be drawn. It forces choices on 16 year olds which result in large parts of the cohort effectively ruling out engineering (or science) at 16. The emerging structure of the labour market, in which a large proportion of high-status jobs do not require higher mathematics, or indeed any very specific sort of degree[2] increases the numbers who decide not to commit themselves irrevocably to specific maths/science/engineering choices.

We need, as a matter of urgency, to secure reforms in the post-16 sector which maximise rather than minimise the potential pool of engineering HE entrants. This includes a response to the mathematics problems of 16 year olds, especially those who have followed less advanced GCSE courses, and examination of the level and consistency of mathematics provision within engineering and pre-engineering courses. It also involves a rethinking of the new GNVQs, which might seem to be addressing mathematics requirements but are in fact doing no such thing.

Current choices

At present all 16 year olds who might select engineering will have followed a GCSE mathematics courses. However, not all will have followed the same one. There are three overlapping maths syllabi. Only the "top" one would normally be considered appropriate for A level mathematics entry. However, many quite mathematically able young people will have followed the intermediate syllabus (in order to be confident of a C grade): and will as a result have done very little algebra.[3]

At 16 the choices for potential engineers are between a number of established alternatives, and some emerging ones.

1. To select 3 "A" levels (or, increasingly often, 3 plus an AS level, or 4 A levels)

2. To select a full-time college-based BTEC course leading to a National Diploma (This will remain an option for some time, although NVQs or GNVQs are expected to replace all Diplomas eventually.)

3. To obtain an apprenticeship and study part-time at college

4. To take a GNVQ (General National Vocational Qualification), alone or with an A level.

5. To combine a GNVQ, or A levels, with one or more intermediate awards in academic subjects. This option is fairly new, and it is not yet clear whether it will be adopted by significant numbers of students.

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2 A recent study indicated that half the advertisements for "graduate" recruits did not specify the degree subject required in any way. See evidence cited in Atkins, M.J., Beattie, J. & Dockrell, W.B. (1993) Assessment Issues in Higher Education (Employment Department)

3 A candidate who enters for the top papers and fails to obtain an A, B or C grade receives only an 'ungraded' GCSE. On the intermediate syllabus a C is the top grade possible. It is commonly felt that it is easier to get a C on the intermediate than on the top paper, so many young people will be entered for the former, and not the latter.

1. Issues associated with A level maths

A level maths poses problems for engineering recruitment because of

a. the uniquely specialised nature of A level choice
b. the perceived difficulty of maths A level

We would emphasise that b) is only a serious problem because of a). Young people in other countries do not find maths easier, or enjoy it more, than those in the UK: but because elsewhere it remains compulsory for everyone until age 18, there is no relative disadvantage associated with its study. The worry in England is that, by choosing maths, one may end up with a poor grade, or failing outright: while a contemporary of equal ability who selects another subject will do better, and have enhanced chances of entry into higher education.

The perception that maths is "harder" is accurate[4]: but the difference is not huge, and is far more evident for Further Maths than for Maths A level.[5] Moreover, HE entry in maths and science subjects generally requires lower A level grades, thus redressing the balance. A number of innovative Maths A levels have been introduced in recent years. Further changes within the current 3 A level system - which in practice would mean making Maths A level easier - are unlikely to have much effect on 16 year olds' choices or engineering recruitment, but would have other undesirable implications. Specifically:

a. We have no reason to suppose that such change would hugely increase the numbers taking Maths (which remains the second most popular single A level, difficulty notwithstanding). Decisions against maths (and science) are related to young people's perceptions of labour market opportunities, and desire to keep a wide range of desirable options open, and will not be altered greatly simply by changes to curriculum content .

b. European countries are generally increasing the maths demands made of students, as part of the perceived need to increase educational standards.

c. A level Maths serves the needs of many HE courses other than engineering. In recent years, many HE institutions have provided bridge courses for entrants with single rather than double maths: but further reduction in content would put three year degrees under strain at a time when there is no government support for increased funding.

Solutions to the "disincentive" effect of A level maths should be sought instead in structural changes to post-16 provision. The arguments for broader study post-16 have been well-rehearsed, by the Higginson report among others, and have lost none of their force. Evidence of the demand for less specialisation can be found in, for example, AS Maths entries: small, but considerably higher than for any other single-subject AS level. However, if A levels are to remain largely unreformed, then alternative ways of continuing mathematics learning post-16 are needed.

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4 i.e. students with equal grades at A levels are likely to get lower grades on maths A levels (and physics) than on arts or other science ones.

5 There are far more single than double entries (i.e. Maths alone rather than Maths plus Further Maths). Further Maths is not taken alone. The division replaces the old Pure/Applied split.

2. Issues associated with BTEC awards and NVQs

The most popular alternative to A levels in full time study is one of the BTEC awards.[6] 16 year olds entering BTEC courses make decisions "for" or "against" BTEC courses which are more absolute and irreversible even than those made by A level students. The fact that **most students following BTEC courses receive no formal mathematics instruction at all** is a key reason for this "foreclosure" of options. It makes it virtually impossible for young people who have followed BTEC courses other than those in engineering and science to enter mathematically demanding courses (including engineering) at age 18.

The contrast with Europe is enormous. All European countries require mathematics not only for their academic 16-19 year olds but also for all those following technical or vocational courses. They do so partly in order to keep progression routes open, and partly because of the subject's intrinsic importance. BTEC's requirement that "common skills" be integrated into the curriculum has no such effect. Mathematics is generally neglected[7].Even in courses (notably engineering) where mathematics *is* taught separately, standards tend to be highly variable. As Alan Smithers[8] has pointed out , the variability of their mathematics preparation is an important factor behind drop-out from engineering degrees by BTEC entrants.

An additional issue of particular relevance to BTEC engineering and science courses arises from the way GCSE mathematics is taught. BTEC groups (unlike A level maths groups) are likely to contain young people who have followed two different GCSE syllabi, one of which requires very little algebra. This heterogeneity is likely to increase yet further under National Curriculum requirements which encourage teachers to work in terms of a number of different "levels" for a given age group. Classes with very different prior achievements make teaching difficult, especially in tightly structured subjects such as mathematics, and may indicate a need for a well-defined "bridge" course. (These points apply equally to students entering Diploma courses via BTEC First Diplomas rather than directly from GCSE).

Over the next few years, the expectations is that BTEC awards will all be converted into NVQs (National Vocational Qualifications) or GNVQs (General NVQs). GNVQs are discussed below: while at present NVQs are not generally taken by potential higher education candidates. However, it is important to emphasise that a switch to **NVQs will do nothing to introduce explicit mathematics teaching into vocational courses.** On the contrary: evidence to date indicates that NVQs are associated with a reduction in explicit mathematics provision.

3. The GNVQ option

Current government policy envisages that, within the next few years, General National Vocational Qualifications (GNVQs) will become the major alternative to A levels for full-time study post-16, replacing current provision (especially BTEC Diplomas.) The major awarding bodies are competing fiercely for this market.

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6 This is the major educational route for engineering technicians, and for them frequently leads on to an HND or degree. Most BTEC entries are in other areas however: e.g. business, tourism.

7 See Alison Wolf, *Mathematics for Vocational Students: Contrasting Provision and Consequences.* Discussion Paper 23: NIESR (1992)

8 Alan Smithers *The Vocational Route into Higher Education* School of Education, University of Manchester

It is unclear how far engineering provision for 16-18 year olds will become GNVQ rather than NVQ-based. However, a good number of *potential* entrants to higher education engineering and technical courses are likely to select the GNVQ route. It is therefore crucial that as many GNVQ courses as possible provide their students with mathematics which makes this an option in actuality.

At first sight, GNVQs appear to offer a general improvement on current provision, by requiring that the "core skill" of "application of number" be accredited in all courses. In principle, therefore, GNVQs offer young people the possibility of, for example,

> combining a GNVQ in science or engineering with an A level in a different area, while still maintaining the maths coverage necessary for higher education courses in engineering or science
>
> or
>
> following a GNVQ in, say, business studies, while still keeping open the possibility of moving to a more technical subject in HE.

Unfortunately the way in which the GNVQ "application of number" requirements are actually being implemented threatens to further attenuate the mathematics content of the non-A level route, not to strengthen it Rather than increasing it may actually decrease the numbers able to cope with engineering degrees.

The fact that GNVQs refer specifically to "application of number" gives the impression that these new awards will provide a broad general education that raises mathematics standards post-16 in a way that most A level and BTEC awards have not. The dismal gap between rhetoric and reality results from decisions by the National Council for Vocational Qualifications, responsible for the design and accreditation of the awards. They are strongly opposed to the idea that mathematics should be taught or assessed separately within GNVQ courses. Instead "application of number" is to be delivered entirely in the context of other, applied activities.

To make this possible, the number requirements are pitched at a level of extreme generality —

> *e.g. "reasonable estimates are made in order to verify the results of calculations"*

and are identical across all GNVQs. The claim is that the level of mathematics reached in all GNVQs will likewise be identical. Unfortunately, this claim flies in the face of both evidence and argument.

The rationale for the GNVQ approach is the (correct) proposition that applying mathematics is a skill over and above that required for computation. However, we know from previous curriculum experiments and other awards that unless mathematics has a separate timetabled allocation, it will be given low priority, and in many cases effectively disappear from the curriculum. We also know that it is impossible to "extract" statements about mathematical attainment from other activities in a reliable or consistent way[9], and that, within the constraints of a subject curriculum (whether this

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[9] See Alison Wolf, Assessing Core Skills: Wisdom or Wild Goose Chase. *Cambridge J. of Education* (1991); M. Cresswell, Describing Examination Performance, *Educ. Studies* (1987)

be history, mechanics, tourism, or catering), it is very difficult to cover more than a very limited range of mathematics.

In the face of concerted pressure from the profession, NCVQ has agreed that the engineering GNVQ will have a separately specified mathematics unit. This, at best. maintains the status quo: - it does nothing to strengthen the mathematics of 16 year olds who have not decided definitely to become engineers. The current GNVQ approach also comes into direct conflict with the aim of assisting progression even *within* a given curriculum area, since it takes no explicit account of the prerequisites for degree level work.

The GNVQ structure is potentially able to offer major improvements in the provision of mathematics in the 16 - 18 curriculum. and so increase the pool of potential engineering and technical students. In actuality it fails, at present, to achieve either goal and is in urgent need of reform.

4. Emerging Intermediate Qualifications

GNVQs could, in principle, increase flexibility and mathematics preparation among non-A level students. However, most academic students are likely to continue to choose a full A level programme, especially given the expected increase in competition for higher education. Continued rejection of A level reform (such as making 5, not 3, subjects the norm) will restrict the proportion choosing an A level in mathematics.

The government's preferred method of broadening the curriculum is via "Advanced Supplementary" (AS) level examinations. AS levels are equivalent to half an A level: and the examination boards have followed the government's instructions, maintaining the level of difficulty and simply reducing content coverage. As a result, 2 AS levels are in practice experienced as harder than one A level, and the reform is generally seen as a failure, with few candidates. Even though mathematics is easily the most popular single subject AS level,[10] AS levels are not a viable mechanism for improving mathematics provision post-16.

As emphasised throughout this paper, the key consideration for the future of engineering is how to maximise the number of 18 year olds who *could* choose engineering, and have not precluded it by choices at 16 which, most damagingly, exclude all mathematics. It is also important that *adults* be offered a route of study back into engineering and science as well as into the arts and social sciences subjects which currently predominate. (The low number of adult returners in technical and scientific studies is related to the absence of any mathematics programmes in FE other than GCSE retakes and A level.)

With a full-scale reform of A levels unlikely in the near future, we need alternative ways of encouraging young people to broaden their sixth form study, and providing mathematics courses for older students. One possible way forward is being piloted by the Northern Examinations Board in conjunction with the Headmasters Conference. They are introducing a new *intermediate* award ("E" level) designed to offer a higher qualification than GCSE, and taken after a one-year course which could also be the first year of an A level programme of study. The programmes of study followed by most A level students leave room for additional subjects and options, which could include intermediate courses of this type. Qualifications at this level could be identified as entry

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10 General Studies has the largest entry.

requirements by university departments, or used within a "bridge" course, and might be very attractive to adult returners aiming for technician or degree awards.

A more systematic approach would be to revitalise the government's original ideas for an Advanced Diploma. If such a Diploma required that mathematics (and English) be studied at a level higher than GCSE (though lower than A level) it would be possible to introduce more compulsory mathematics into the 16-18 curriculum without full scale A level reform. A restructured GNVQ in which "application of number" and "communication" were taught and delivered separately would meet Diploma requirements.

5. Conclusion

Mathematics provision in post-compulsory education is in desperate need of reform. We fail to provide the focused teaching needed to bring most students to a high level of attainment, and the structure of qualifications gives them few incentives to continue mathematics studies. This is markedly and increasingly out of line with practice among our European neighbours, or with the requirements of a modern technological society.

A number of options present themselves (and are not mutually exclusive).

(a) Separate mathematics teaching and assessment in GNVQs.

If, as the government envisages, GNVQs become the main alternative to A levels, reform of the current 'core skills' approach is very important. Such changes would mean an increase in the amount of targeted mathematics teaching. It should also make the award more transparent and attractive to higher education selectors, and improve the transition between courses.

(b) Intermediate mathematics qualifications taken alongside A levels, GNVQs or NVQs, or by adult returners. Such courses need not all be of the same type or content (and AS syllabuses and modular A levels offer a variety of development ideas). Such courses would be of particular relevance to those with lower GCSE/National Curriculum attainments.

(c) A level reform

A move away from the current 3 A level model would certainly increase the numbers who take Mathematics, and are therefore in a position to take engineering science and related degrees. However, this reform would affect only the top 30% of the attainment range.

(d) Revitalisation of the government's proposal for an Advanced Diploma. If such a Diploma required mathematics (and English) at quite a high level (e.g. National Curriculum level 9 or 10/GCSE A or B *and/or* further study and qualification post-16) this would give enormous impetus to the provision of mathematics in sixth forms and FE colleges.

(e) A change in higher education entry requirements to encompass options other than "GCSE A-C" or "Maths A level": and so encourage provision and take-up of explicit maths options.

Without reforms along these lines, and the changes in qualification structure implied, recruitment into engineering and the mathematics attainment of our young people will remain serious problems.