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# Engineering students' knowledge of mechanics upon arrival: Expectation and reality

Stephen Lee, Martin C. Harrison and Carol L. Robinson

## Abstract

**In recent years there has been an increasing awareness of a lack of knowledge of mechanics amongst engineering students entering English universities. In this paper, the authors investigate the level of knowledge of mechanics which lecturers commonly expect from students entering university. They also review students' actual knowledge upon arrival. This research was carried out by implementing several research methods, including a survey of 497 schools in England; a survey of over 1,000 engineering students; results from a mechanics diagnostic test sat by 451 engineering students and a survey and follow-up interviews of academic staff. Findings from these indicate that there is a considerable difference between academic expectation and the reality of students' prior knowledge of mechanics.**

## Introduction

In this paper engineering students' prior knowledge of mechanics upon entry to English universities will be considered. In particular, analysis of questionnaire surveys, tests and interviews carried out by the authors will be detailed. It will be seen that there are significant differences between academics' expectations and students' actual knowledge of mechanics upon their entry to university.

In 2004, the authors were commissioned by the UK Higher Education Academy Engineering Subject Centre to investigate students' knowledge of mechanics upon entry to university in England. The detailed results of their work are available in Robinson *et al* (2005). In this paper some discussion of that report will be undertaken, including results from a questionnaire mailed to 497 schools in England which gathered information on the uptake and availability of mechanics, results from a questionnaire completed by over 1,000 undergraduate engineering students, and analysis from surveying and conducting follow-up interviews with engineering academics on what prior knowledge of mechanics they expect from new students. In addition, changes in pre-university qualifications will be reviewed along with analysis of a mechanics diagnostic test created by the authors and sat by 451 engineering students.

Firstly, the paper considers what mechanics is available and being studied in schools in England. Then a review is given of the mechanics that engineering students have studied prior to entering university. Following this, the expectations that engineering academics have of their students' knowledge of mechanics upon arrival at university is reviewed. Finally, conclusions on the difference between the *expected* and *actual* knowledge of mechanics of students entering university will be drawn.

## Background

For many years universities in the UK have been aware of the 'mathematics problem': the declining levels of mathematical expertise possessed by engineering (and other) students upon entry to university. In the past decade much research has been undertaken to address this concern, including several major reports such as 'Tackling the Mathematics Problem' (London Mathematical Society, the Institute of Mathematics and its Applications and the Royal Statistical Society, 1995) and 'Measuring the Mathematics Problem' (Hawkes and Savage, 2000). Techniques for tackling the problem, including diagnostic testing and follow-up support are discussed in these reports, as well as by Armstrong and Croft (1999).

There has been little mention of the associated 'mechanics problem' that has come to the attention of engineering educators in recent years. Kitchen et al. (1997) expressed concern that no mechanics was included in the core material for A-level mathematics (the core material is the compulsory material that all students must study for certification in AS and A-level mathematics, the traditional

qualifications for 16-19 year olds in England). More recently, Mustoe (2004) expressed concern about the effect on mechanics of a change in the structure of A-level mathematics in September 2004. This change is detailed in Porkess (2003). Essentially, the number of applied modules that students are required to study for an A-level in mathematics was reduced from three modules to two modules. Consequently, there is much interest from university engineering departments in establishing the *actual availability* and *uptake* of applied mathematics modules in schools, specifically mechanics modules. It should be noted here that, in addition to the mechanics studied as part of A-level mathematics, students who studied A-level physics (a requirement for the majority of engineers) do encounter some elementary mechanics in their compulsory physics modules.

## What mechanics is available and being studied as part of mathematics courses in schools?

A review of the situation in schools in England, prior to the changes in September 2004, was carried out by producing and mailing a questionnaire to 497 (18%) of the 2,717 schools in England where students studied for A-levels (in any subject). Full details of the questionnaire can be seen in Robinson *et al* (2005). Here, some of the major findings are reported.

## Schools questionnaire results

242 schools in total replied to the questionnaire, a return rate of 49%. Within these schools, there were some 13,754 students studying either AS or A-level mathematics courses. Firstly, the results on the availability of mechanics modules are reviewed. More detailed analysis of all applied modules is reported in Lee *et al* (2005).

Column two of Table 1 shows the percentage of the 497 schools that did not offer any mechanics modules and the percentage of the 13,754 students in the sample who could not study any mechanics modules. It can be seen that over 5% of schools in the sample do not offer any mechanics. Consequently, potential engineering students attending one of these schools have no opportunity to study mechanics modules within AS or A-level mathematics.

Column three of Table 1 shows the percentage of schools which did not offer any module, or at the most offered one module, of mechanics. It also shows the percentage of the 13,754 students who could study at most one module of mechanics.

**Table 1.** Availability of mechanics modules in schools

| | Mechanics Modules Available | |
|---|---|---|
| | None | At most 1 i.e. none or one |
| % of Schools | 5.35 | 26.34 |
| % of Students | 2.62 | 15.83 |

One of the main purposes of this paper is to establish how much mechanics is available for students to study. The material presented in M1, the first mechanics module, is an introduction to mechanics at a very basic level. Typical topics studied include: force as a vector, equilibrium of a particle, kinematics of motion in a straight line, Newton's laws of motion and linear momentum. Not until students study M2 do they start to encounter more demanding material, such as projectile and circular motion. Traditionally, students would have studied the material in M1 and M2 when mechanics was part of the core material for A-level mathematics (pre-1990s). The results on the availability of mechanics modules show that a significant number of students (approximately 16%) are unable to study mechanics to a level that was once compulsory within the A-level mathematics syllabus.

Until now, the results have focused upon the availability of mechanics modules - there are a significant proportion of students in the sample (some of whom may well wish to become engineers) who are unable to study mechanics beyond M1. However, even if mechanics modules are available, students may not choose them or even be advised not to study them. Hence it is important that the actual uptake of mechanics modules in schools is considered.

Figure 1 shows the percentage of the 13,754 students in the sample that studied mechanics modules. It can be seen that approximately 42% of students studied M1, approximately 18% studied M2 and only 8% studied a higher-level module. Consequently, it can be seen that (in our sample of schools) at most 26% of students study more than a basic mechanics

module (M1). Ostensibly, this suggests that few students who go on to study engineering courses at university may have actually studied more than an elementary amount of mechanics. However, it is possible that a large number of those who studied M2 or higher go on to study such courses as engineering. Later on detail is given of in a survey conducted with undergraduate engineering students to establish what mechanics module they had studied at school.

The data for the school questionnaire was collected in January 2004, prior to the changes to A-level mathematics that took place in September 2004. since then students study at most two applied modules when previously they could study three. As before, students can study more mechanics modules if they study Further Mathematics A-level. In 2006 the authors addressed a similar questionnaire to the same schools to gain an understanding of what effect, if any, the changes in September 2004 had on the availability and uptake of mechanics. The initial findings were presented at the Institute of Mathematics and its Applications (IMA) Fifth Mathematical Education of Engineers conference. These findings indicate that the availability and uptake of mechanics had declined further.

## How much mechanics have students entering university engineering courses actually studied at school?

By reviewing the availability and uptake of mechanics modules in schools, an understanding has been gained of which modules students could study and what percentage actually *do* study them. For example, 42% overall studied M1 but this does not necessarily imply that 42% of *engineering students* entering university have studied M1. In order to establish engineering students' knowledge of mechanics upon entry to university, two methods were used: a questionnaire and a mechanics diagnostic test.

## Questionnaire to engineering undergraduates

A simple, one-page questionnaire was produced in autumn 2003 to obtain details of which A-level mathematics modules students had studied prior to entering university. This information is not available to universities via the Universities and College Admissions Service (UCAS). Loughborough University is situated in the East Midlands and has approximately 12,000 students, including over 3,000 engineering students. In the academic year 2003/04, 318 first year engineering students who had studied A-level mathematics completed the questionnaire correctly. This was a response rate of 50% of the first year engineering students surveyed. In 2004/05 a substantial increase in the response rate (from 50% to over 90%) was seen, the primary reason for this being the way in which the questionnaire was administrated. More details are given in Robinson et al. (2005). The comparative numbers of mechanics modules studied by engineering students can be seen in Figure 2.

From Figure 2 it can be seen that the 498 engineering students in autumn 2004 gave similar responses to the 318 engineering students in autumn 2003. In both years approximately 9% of students had not studied any mechanics modules, with a further 24% having studied only one module of mechanics. Hence, 33% of the sample of Loughborough University engineering students had studied, at most, one module of mechanics. This means that one in three students commencing an engineering degree (that will require them to use and apply mechanics concepts and theory) will have very little prior mechanics knowledge. Subsequently, many of

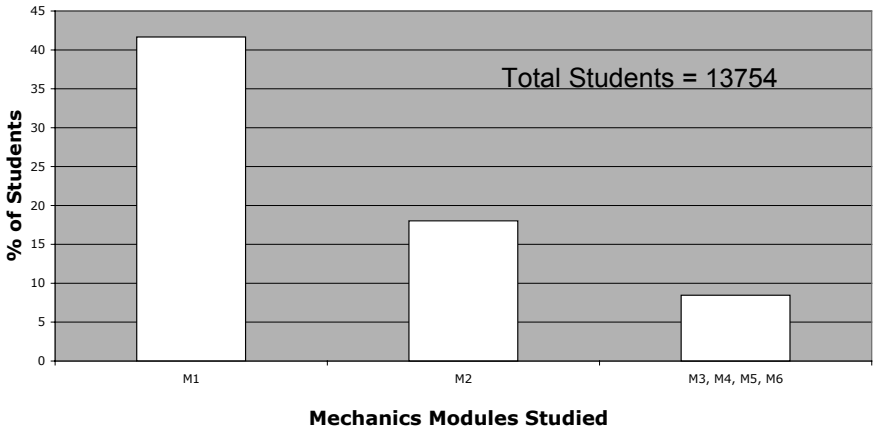



**Figure 1.** Percentage of students studying mechanics modules in schools

these students may find themselves struggling with their first university module of mechanics unless no prior knowledge is assumed by the teacher. From Figure 2 it can also be deduced that 91% of Loughborough University engineering students have studied at least one module of mechanics, which compares well with the 42% of the students in the survey of schools who had studied M1.

In addition to Loughborough University students, in 2004/05 approximately 270 students from two other universities (University of Nottingham and University of Leicester) completed the questionnaire. These universities are the closest geographically to Loughborough. The University of Nottingham has a large Engineering Faculty and the Department of Engineering at the University of Leicester is relatively small.

Figure 3 shows the percentage of engineering students at each of the three universities who had studied a given number of mechanics modules. The percentages for Loughborough University and the University of Nottingham are similar (no statistically significant difference was found when using a test $\chi^2$), but the results from the University of Leicester indicate that prior knowledge of mechanics is less than at the other two universities. However, there were only a small number of replies (39) from Leicester and therefore the results from the other two universities may give a more accurate reflection of the national situation.

Aggregating the data from 2003/04 and 2004/05 over all three universities it becomes apparent that the percentage of all students studying mechanics at school is significantly different to the percentage of students in the first year of an engineering course who had studied mechanics at school. For example, approximately 91% (Figures 2 and 3) of engineering students had studied M1 compared to 42% (Figure 1) of

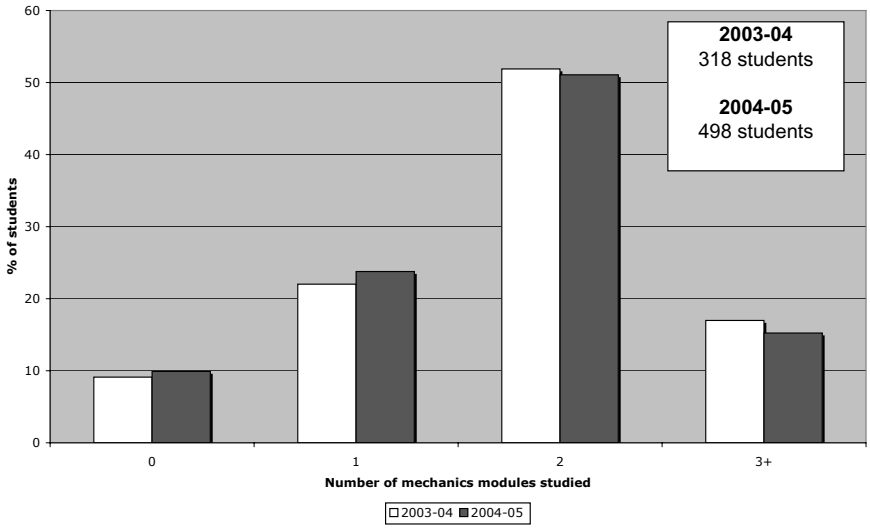



**Figure 2.**
Percentage of Loughborough University engineering students who studied a given number of mechanics modules

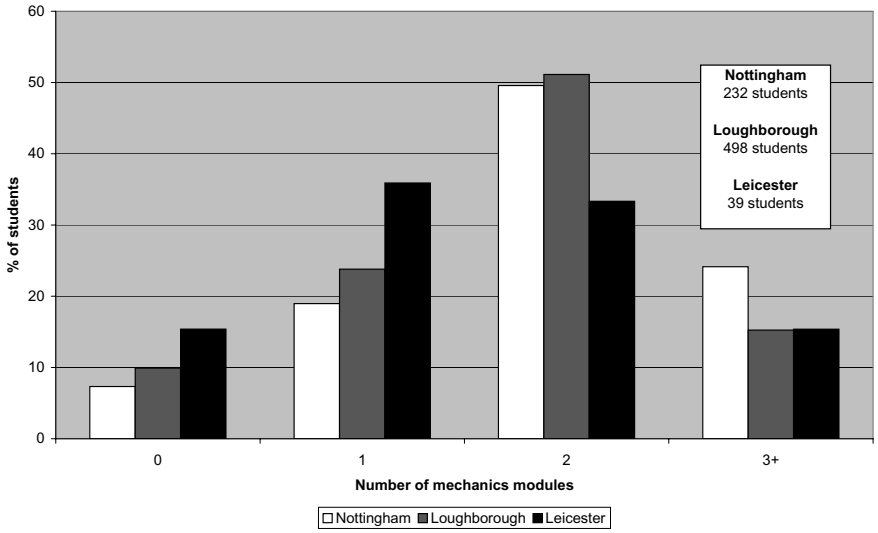



**Figure 3.**
Percentage of students from three universities studying a given number of mechanics modules

students in school. But perhaps more interesting are the percentages of those who had studied at least M1 and M2. Approximately 68% (Figures 2 and 3) of engineering students had studied two or more modules of mechanics compared to, at most, 26% (Figure 1) of students in schools. Thus, it would appear that those going on to study engineering at university have studied more modules of mechanics than indicated by the uptake in schools. However, there is still obvious concern over the large percentage (32%) of engineering students who have studied little or no mechanics (i.e. at most M1).

## Mechanics diagnostic testing of Loughborough University undergraduates

In addition to the questionnaire, a multiple-choice mechanics diagnostic test was developed to ascertain the level of knowledge of incoming Loughborough University students with respect to the mechanics modules studied as part of A-level mathematics. The fact that a student has studied a module at school does not necessarily indicate an understanding of the material - the student may have failed a mechanics module but still have passed A-level mathematics at the required grade. The test contained 24 questions: three on each of the five topics in M1 and one on each of the five topics in M2, along with four additional questions which included two misconception questions.

The mechanics diagnostic test was sat by 451 engineering students in autumn 2004. Students' results for the test in relation to the number of modules of mechanics they had studied are given in Table 2. There it can be seen that the average diagnostic test mark for the group of 96 students who had studied one module of mechanics was 65.9%. Similarly, the average diagnostic test mark for the group of 208 students who had studied two modules of mechanics was 74.6% (i.e. 9% higher than the group average for those who had studied only one module of mechanics). Finally, those who had studied three or more modules of mechanics had the highest group diagnostic test average of 81.3%.

The performance of different groups of students in the 14 M1 level questions was reviewed. In these questions students who had studied two or more mechanics modules in A-level mathematics scored, on average, 5% more then those who had previously only studied M1. This may be due to the fact that students who had studied more then one mechanics module had studied it more recently (it may have been the case that students who had only studied M1 would have studied it 12 to 18 months previously). In addition, such students will have studied more mechanics and over a longer period of time and this will have given them more opportunity to absorb the basic concepts. In five of the 14 questions a higher percentage of correct answers was obtained by students who had only studied M1, although in each of these questions there was a difference (in the percentage of correct responses) of less then 2%. Students who had studied two or more mechanics modules scored considerably higher (up to 23%) in three specific questions (on resolving forces, pulleys and velocity-time charts).

Students who had not studied A-level mathematics or simply could not recall which modules they studied were in the 'Don't Know' group. This large (50 students) group's average mark in the diagnostic test (48.2%) was significantly lower than those who had studied A-level mathematics. The performance of this group certainly raises concern, however, this is not the focus of this paper.

These results indicate that the diagnostic test had discriminated (statistically significantly using the $x^2$ test) between the students in terms of the number of mechanics modules they had studied. Furthermore, when the results from the questionnaire to students, the diagnostic test and the questionnaire to schools are considered, an understanding of the knowledge of mechanics with which students are entering

**Table 2.** Mechanics diagnostic test results for groups of students depending on how many A-level mechanics modules studied

| Number of mechanics modules | 0 | 1 | 2 | 3+ | Don't Know | Overall |
|---|---|---|---|---|---|---|
| Number of Students | 30 | 96 | 208 | 67 | 50 | 451 |
| Mechanics Diagnostic Test mean | 59.9 | 65.9 | 74.6 | 81.3 | 48.2 | 69.8 |

university has been gained. However, it also needs to be established exactly what knowledge of mechanics academics expect students to have and thus establish if there are any discrepancies between expectation and reality. The next section discusses this issue.

## How much mechanics do academics expect students entering university to have studied?

An online questionnaire and follow-up interviews were used to ascertain academics' awareness of the prior mechanics knowledge of their intake. The questionnaire received a total of 33 responses from academics in 19 different universities and follow-up interviews were held with eight academics. The respondents represented a wide cross-section of universities and engineering departments, and a large number of engineering students (over 4,000) for whom a knowledge of mechanics was important. It was found that only 17% of the respondents were aware of the mechanics modules that their students had studied within A-level mathematics. This lack of awareness gives cause for concern. If they assume no prior knowledge of mechanics, as 11 of the 26 who answered this question did, then the only problem may be that those who had studied mechanics become bored. However, if they do assume a given level of prior mechanics knowledge then students without this assumed knowledge may quickly feel disadvantaged and struggle with the work, which could consequently lead them to give up the course. In fact, 15 out of 26 academics (58%) assumed a knowledge of mechanics that their students would not necessarily have.

As well as having little awareness of their students' prior knowledge of mechanics, the academics showed a lack of awareness of developments in A-levels. In at least a third of the departments represented by the academics in this survey there was not one member of staff who monitored developments in A-level mathematics. This is a worrying statistic and, with the recent changes in A-level mathematics, one which will have implications for the students studying in these departments.

## Concluding remarks

This paper has considered engineering students' prior knowledge of mechanics upon entry to English universities. In particular, three areas have been reviewed: students' opportunity to study mechanics at school, engineering students' prior knowledge of mechanics upon entry to university and academics' perceptions of the students' prior knowledge.

Many interesting statistics have been collected which have highlighted several areas of concern for engineering educators. For example, it was found that 26% of schools offered at most one module of mechanics and at most 26% of 13,754 school students in the sample actually studied more than a basic mechanics module (Table 1 and Figure 1). This indicates that attention should be given to the availability and uptake of mechanics in schools. It can only be beneficial for those involved in teaching engineering at university if students have encountered mechanics before beginning an undergraduate course. Studying mechanics in A-level mathematics will have enabled the material to be presented over a time scale which is likely to have been several months. At university, even if academics assume students have little or no knowledge of mechanics (which was found not to be the case) students are still only likely to receive a small number of lectures on basic mechanics. Feedback from two interviews indicated that this can be from four to eight hours of lectures. Thus, time to absorb the crucial basic theories and strategies for setting up and solving mechanics problems will not have been available.

It was more encouraging to see that a higher percentage (68%) of university engineering students had studied two modules of mechanics compared to the percentage (at most 26%) of students in schools. However, there is still a great concern over the large percentage (32%) of engineering students entering university having studied little or no mechanics. This concern was supported by the students' results in the mechanics diagnostic test, which indicated that those who had previously studied more mechanics modules did significantly better than those who had studied fewer modules. In addition, the fact that many engineering academics still expect students to have studied a significant amount of mechanics heightens the concern for those students that have little or no prior knowledge. Expectation and reality of prior study are not in alignment.

It is not easy to effect changes in schools so that more students study mechanics. It will therefore be those at the school-university transition (i.e. first year module lecturers) who will need to make suitable adjustments. There is no obvious solution, but by reviewing good

practice in related areas such as mathematics, then perhaps improvements can be made. Such good practice includes diagnostic testing students upon entry (and offering suitable and appropriate follow-up support) and establishing mathematics support centres incorporating help and resources for mechanics. Indeed, such action is already being taken - the Higher Education Academy Engineering Subject Centre is currently funding a mini-project to create leaflets on introductory mechanics topics and these are freely available via the **math**centre website (www.mathcentre.ac.uk). At Loughborough University, from the next academic year, three hours of dedicated mechanics support will be available in the Mathematics Learning Support Centre. Given provision of adequate support in mechanics, those who have studied little or no mechanics prior to entering university could be enabled to succeed.

An important point this research has raised is that academics need to ensure that they are aware of their students' prior knowledge of the subject. This is imperative in the current climate where changes have occurred in many pre-university qualifications. ■

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