

Graduates' Views on the Undergraduate Mathematics Curriculum*

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1 Executive Summary

In Winter 2011 we surveyed the views of 428 mathematics graduates from the 2008/9 graduating cohort. Each graduate was asked to reflect on the knowledge/skills they believed that they developed during their mathematical study, and to assess how useful these skills have been during their career to date. We were also able to benchmark these data against an earlier survey of incoming undergraduates' expectations.

Our overall goal was to determine whether the higher education mathematics syllabus adequately prepares students for the workplace.

We found a mixed picture:

- An overwhelming majority of graduates believed that they successfully developed generic cognitive skills during their studies (e.g. logical reasoning, critical thinking and problem solving). Furthermore, there was widespread agreement that these skills are useful in the workplace.
- However, fewer students believed that their studies had developed generic non-cognitive skills such as making presentations, oral and written communication, team working or computer literacy. All these skills were considered to be useful in the workplace, but are apparently not well developed by studying undergraduate mathematics. Furthermore, we found that incoming undergraduates *expected* to develop these non-cognitive generic skills during their mathematical study, suggesting that there is a mismatch between students' expectations and outcomes.
- When asked to select what skill graduates wished they had had the opportunity to develop more during their mathematical studies, the most commonly selected was "applying mathematics to the real world". Over 90% of incoming undergraduates expected to develop this skill, whereas only around 60% of graduates believed that they had.

This report raises two issues to consider. First, whether the mathematical community is (or should be) satisfied with the range of skills that graduates perceive the current higher education curriculum to develop. And second, if the community is satisfied by the current situation, how the apparent mismatch we observed between incoming students' expectations and graduates' perceived outcomes can be addressed.

2 Introduction

This document reports the outcome of a survey of recent graduates of mathematics programmes across the UK. The aim of the study was to explore what parts of the higher education curriculum graduates value having studied, and what else they feel they would have benefited from, had it been included.

Several recent studies have focused on the specific mathematical requirements of particular industries (including banking, nursing and manufacturing, e.g. Hoyles, Noss, & Pozzi, 2001; Noss & Hoyles, 1996; Smith, 1999), but these investigations are perhaps not of direct use for a would-be curriculum reformer: clearly, most mathematics graduates will not go into nursing. To partially address this issue, Wood (2010) interviewed 18 recent mathematics graduates (from Australian universities) about their transition to the workplace in a variety of different industries. She found a mismatch between the skills graduates believed they need for the workplace, and those they believed they developed during their undergraduate studies. In particular, her participants noted a lack of generic skill development in their courses (communication, team-working etc.). She concluded:

While it is important that graduates are able to perform mathematical and computing techniques and know the relevant jargon and notations, it is essential that they are able to communicate their knowledge in a variety of circumstances and work in multidisciplinary teams in the workplace. (p. 197).

Our goal in this survey was twofold. First, to ask similar questions to those addressed by Wood (2010), but in the context of the UK higher education sector. Second, to broaden the scope of Wood's study by asking considerably more graduates to reflect on their transition to the workplace (or further study) than would be possible using an interview approach.

Consequently, we adopted a similar approach to that used by Hanson and Overton (2010a, 2010b) in their study of chemistry and physics graduates, by surveying recent mathematics graduates from UK universities. We focused on the 2008/9 graduating cohort, so that by the time of the survey (November 2011 – February 2012), participants had had approaching two and a half year's experience of work or postgraduate study. Thus participants would have had sufficient time to gain an understanding of the skills requirements of their employment (or study), while still retaining a memory of what they had learnt at university.

3 Method

3.1 Participant recruitment

We first approached the head of each UK mathematics department, seeking their support for the survey. Of the 68 heads contacted, 54 (79%) supported the survey, 1 declined to, and the remainder did not respond (after a reminder). We then contacted all 68 institutions' careers/alumni offices with a request that they send an email inviting their mathematics graduates from 2008/9 to take part in the survey (indicating that the survey had the support of their mathematics department where appropriate). Graduates who wished to take part in the survey clicked a link in the email, which took them to the survey website. To encourage email recipients to complete the survey, a prize draw was offered as an incentive to participants.

The invitation email was sent by 40 institutions (59%). Seven universities explicitly declined to participate (10%), and the remainder did not reply (after reminders). One institution contacted their alumni by email and sent copies by post to alumni who did not have a valid email address. Another used text messaging where email addresses were not available.

After a period of approximately eight weeks, institutions who had sent the email were contacted again with a request to send a reminder email, 17 institutions (43%) responded that they had done so. We are extremely grateful for the support of all participating universities and mathematics departments.

3.2 Survey design

The aim of the survey was to determine graduates' views about the skills and knowledge that they had developed during their mathematics degree programmes, and the extent to which these had been useful since graduation.

We first created a list of areas of mathematical knowledge—based on the QAA's (2007) subject benchmark standards—and a list of 'generic skills', based on those used by the 'More Maths Grads' survey of incoming mathematics undergraduates (Challis, Robinson, & Thomlinson, 2009a, 2009b; Robinson, Thomlinson, & Challis, 2009; Thomlinson, Challis, & Robinson, 2009). The full list of knowledge and skills mentioned in the survey are shown in Table 1.

The survey consisted of a website with four pages, and closely followed the structure of Hanson and Overton's (2010a, 2010b) physical sciences surveys. On the first page we asked participants for some background personal information (the university at which they studied, their degree, and their

Mathematical Knowledge
Algebra (e.g. Group Theory, Linear Algebra, Ring Theory etc.)
Analysis
Calculus
Geometry/Topology
Number theory
Differential Equations
Fluid/Solid Mechanics
Mathematical Physics
Mathematical Modelling
Statistics & Probability
Applied Statistics
Mathematical Computing (e.g. MATLAB, MAPLE)
Mathematics Education
History of Mathematics
Generic Skills
Logical Thinking*
Analytical approach to working*
Applying mathematics to real world problems*
Thinking in abstract ways about difficult concepts*
Research skills*
Time management skills*
Written communication*
Oral communication*
Making presentations*
Computer literacy (e.g. MS Office)*
Problem-solving skills
Team-working skills
Independent learning skills

Table 1: The knowledge/skills which we asked participants to reflect upon. Items marked with an asterisk were also included in the More Maths Grads survey (see Section 4.6).

current employment/study status). On the second and third pages we asked participants to consider each of the skills/knowledge listed in Table 1, and to answer two questions:

1. How well did your course assist you in developing the knowledge and skills below?
2. Please indicate the importance of the areas of knowledge and skills listed below for your career so far.

Participants responded using a four-point Likert scale (“A lot”, “Quite a bit”, “Not much”, “Not at all” for the first question above; and “Very important”, “Quite important”, “Not very important” and “Not at all important” for the second question).

On the fourth page we asked participants to select up to five of the items from Table 1 which they, in retrospect, wished they had been given the opportunity to develop more within their undergraduate degree. Participants were also asked to state, using a five point Likert scale (strongly agree, agree, neutral, disagree, strongly disagree), the extent to which they agreed with a quote taken from the Smith Report:

Mathematical training disciplines the mind, develops logical and critical reasoning, and develops analytical and problem-solving skills to a high degree. (Smith, 2004, p. 11)

The fourth page also contained several further questions, which participants were invited to answer using a free text box:

- Please provide any comments which you think may be useful in developing undergraduate mathematics degrees.
- If you had had the opportunity to influence how your undergraduate degree had been taught in order to improve the learning outcomes e.g. teaching style, mode of delivery, peer tutoring/mentoring, what would you suggest?
- Additionally, if you wish, please explain or expand on any of the answers you have given above.

Finally, participants were thanked for their time, and invited to enter the prize draw.

Mission Group	N	Approx %
1994 Group	113	16
Million+ Group	4	–
Russell Group	251	11
University Alliance	8	22
Unaffiliated	52	18

Table 2: The number of responses (with approximate response rate) obtained from each university mission group.

3.3 Response rate

Institutions were asked to advise how many emails had been sent so that response rates to the survey could be monitored (although this was not possible for five universities, implying that all response rate figures reported here are approximate). In total 428 responses were received, which represented an overall approximate response rate of 13% (402 responses were received from the 3213 emails sent by universities who were able to keep track of the number they sent, plus a further 26 responses from universities who were not). There was wide variation in response rates between institutions. The number of responses received from the different university mission groups is shown in Table 2.

One university was able to make their delivery statistics available, shown in Table 3. The survey response rate for this institution was 12%, near to the overall survey response rate of 13%. However, as Table 3 indicates, a significant percentage of this institution’s emails were not opened by their recipients, perhaps indicating that graduates do not always keep universities informed about the email address they most regularly monitor. If this institution’s figures are representative of the situation across the country, then approximately 46% of alumni who read our invitation to participate in the survey did so (although we emphasise that given the difficulty of tracking email deliveries, this figure can only be considered a crude approximation).

Email Status	<i>N</i>	%
Sent	207	100
Not delivered	3	1
Not opened	149	72
Opened	55	27
Survey responses	24	12

Table 3: Email delivery statistics from one participating institution.

Number of Final Year Mathematics Modules	%
All modules	56
Most modules	23
About half my modules	13
Some modules	4

Table 4: A breakdown of how many final year modules taken by participants consisted of mathematics.

4 Results

4.1 Sample characteristics

A total of 428 responses were received. The majority of participants had studied for a bachelors degree (73%), with the remainder having studied for an undergraduate masters degree (MMath or equivalent). To investigate whether participants had taken straight mathematics degrees (as opposed to joint degrees), we asked them to state how many of their final year modules had been mathematics. Responses to this question are shown in Table 4. A minority of participants (6%) had taken a degree containing an industrial placement.

A majority of participants stated that their activities since graduating had either involved mathematics to some extent (30%), to a large extent (19%), or to a very large extent (28%). A large majority of participants were in employment (75%), while a substantial number were engaged in further study (37%), around half of whom were studying as their primary activity (19%). A small minority of participants were unemployed and looking for work (3%). We found few interesting differences in responses between those

who were in work and those in further study (although note below where these differences did arise).

4.2 Development versus importance

We asked each participant to reflect upon the knowledge/skills listed in Table 1 and to estimate (a) how important each had been in their careers to date (whether working, training or undertaking other activities), and (b) how well their course assisted them in developing each.

For each entry in Table 1, we calculated the percentage of participants who responded positively: selected “Very important” or “Quite important” for question (a), and “A lot” or “Quite a lot” for question (b). To facilitate interpretation of these data, we standardised these figures and entered them into a hierarchical cluster analysis (using Ward’s method and a Euclidean squared metric). This resulted in four clusters of knowledge/skills.

4.2.1 Cluster 1

Cluster 1 consisted of knowledge/skills which participants perceived as important in their career, and which they considered had been well developed by their mathematical study. Six different areas of knowledge/skill fell into this cluster, as shown in Figure 1. These tended to be the ‘cognitive skills’ traditionally associated with studying mathematics (logical thinking, problem solving etc).

Recall that we also asked participants to directly respond to a quote from the Smith Report which asserted that studying mathematics develops generic cognitive skills (“Mathematical training disciplines the mind, develops logical and critical reasoning, and develops analytical and problem-solving skills to a high degree”). Responses to this question are shown in Figure 2. A large majority of participants agreed with Smith’s (2004) suggestion (79%). One participant explained:

A mathematics degree definitely exercises the brain, it requires logic, patience, understanding and problem solving skills. It’s extremely hard work, this statement explains it well.

Whether or not studying mathematics *does* develop such skills is a matter of debate among educationalists and psychologists (e.g., Huckstep, 2000, 2007; Inglis & Simpson, 2009; Lehman & Nisbett, 1990; Nisbett, Fong, Lehman, & Cheng, 1987; Thorndike, 1924), but it is clear from these data that there is a widespread belief among mathematics graduates that their study has indeed had this effect.

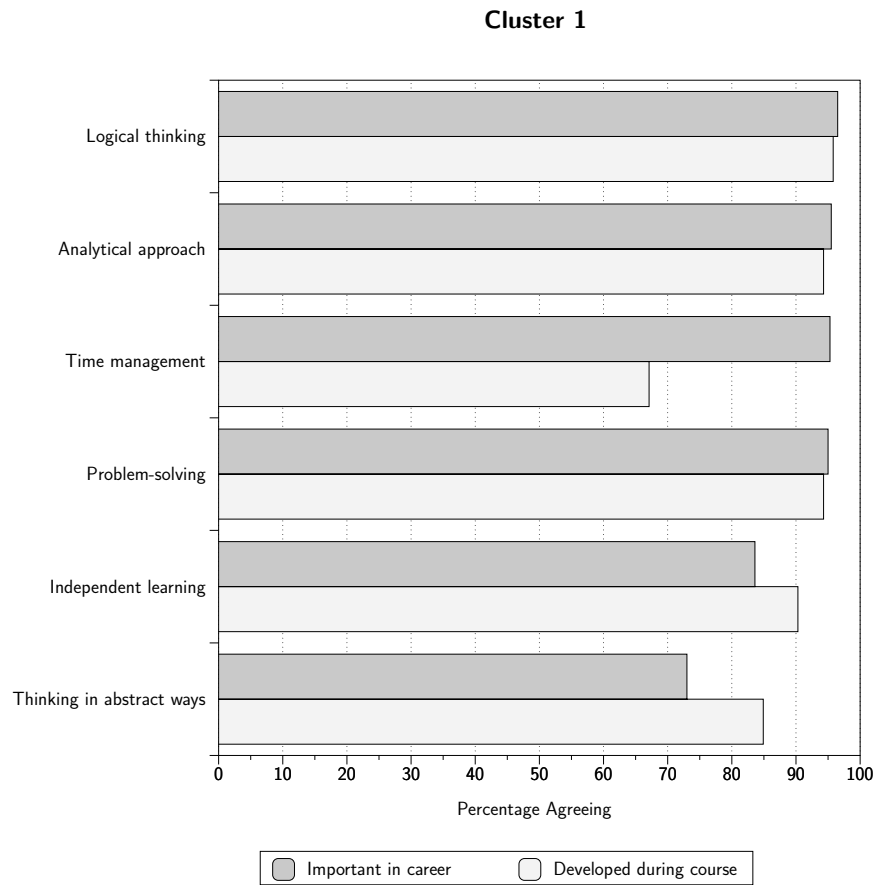


Figure 1: The percentage of participants agreeing that skills/knowledge in Cluster 1 were (a) very/quite important in their career and (b) developed a lot or quite a bit during their course.

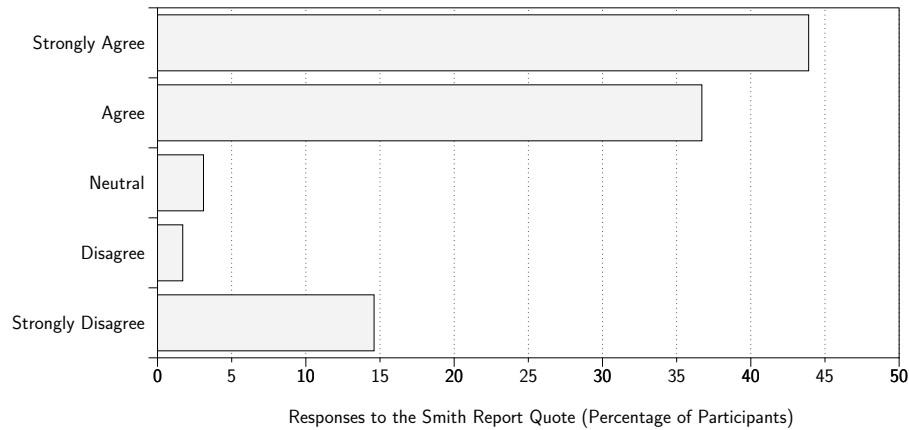


Figure 2: Responses to the Smith Report Quote which asserted that studying mathematics is effective at developing ‘generic cognitive skills’.

4.2.2 Cluster 2

The second cluster of knowledge/skills, shown in Figure 3, was formed of those skills which some participants perceived to be important for their careers, and which were perceived by a reasonable number of participants to have been developed during their course. The cluster included some areas of mathematical knowledge (calculus, analysis differential equations etc.), as well as some generic skills (research skills).

Of particular interest, given the results presented in Section 4.3 was the result for the skill of applying mathematics to the real world: around 65% of participants believed that this was important for their career, and a similar number thought it had been developed during their course.

4.2.3 Cluster 3

The third cluster of knowledge/skills, shown in Figure 4, consisted of areas which were rarely perceived to be important for participants’ careers, but which were perceived by a reasonable number of participants to have been developed during their course.

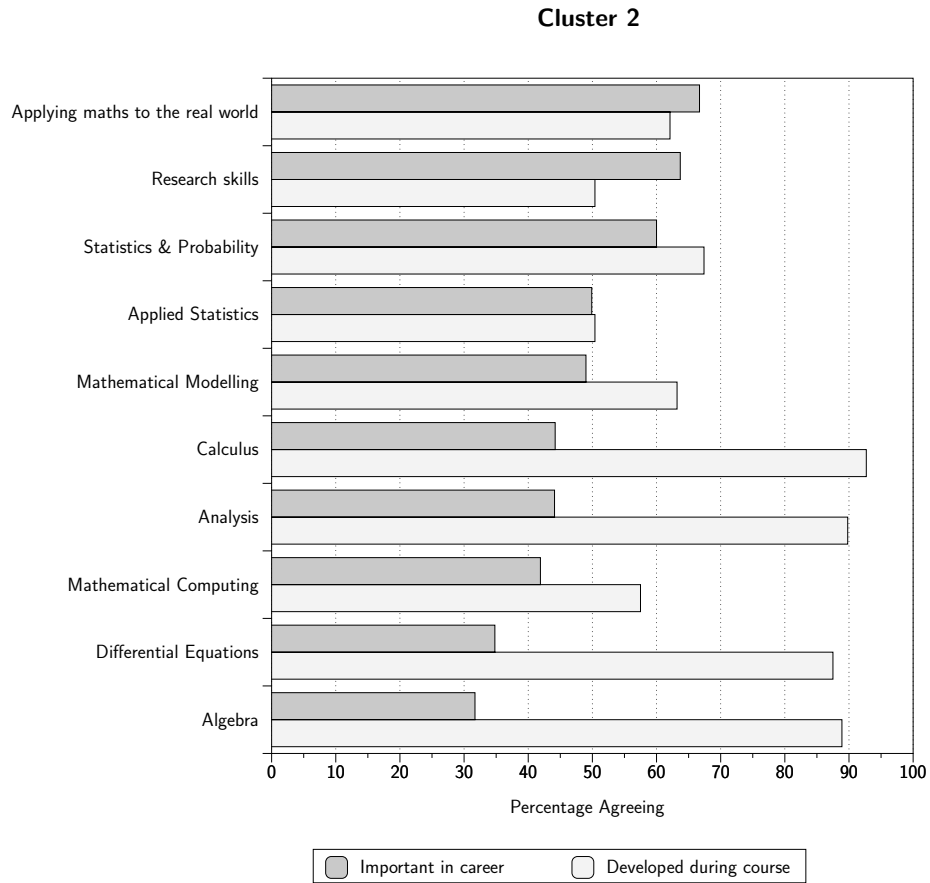


Figure 3: The percentage of participants agreeing that skills/knowledge in Cluster 2 were (a) very/quite important in their career and (b) developed a lot or quite a bit during their course.

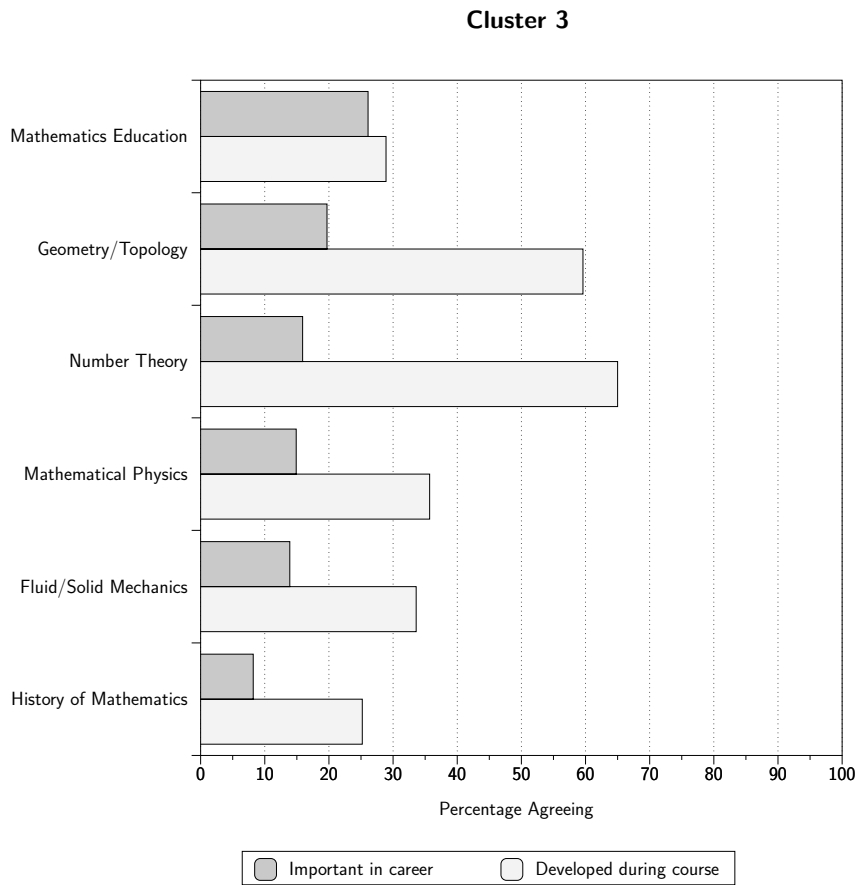


Figure 4: The percentage of participants agreeing that skills/knowledge in Cluster 3 were (a) very/quite important in their career and (b) developed a lot or quite a bit during their course.

4.2.4 Cluster 4

The final cluster of knowledge/skills, shown in Figure 5, consisted of areas which were widely agreed to be important for participants' careers, but which were not widely agreed to have been well developed during their courses. Whereas Cluster 1 consisted of generic cognitive skills (logical thinking etc), Cluster 4 could be classified as consisting of generic non-cognitive skills: oral and written communication, team-working, making presentations and computer literacy. All these areas were considered by the large majority of mathematics graduates to be important for their careers, but only a minority of participants believed that they had been developed during their undergraduate studies.

4.2.5 Workplace versus further study

We found few interesting or surprising differences in responses between those who were in employment as their primary activity, and those who were primarily engaged in further study. We assessed these differences by comparing responses to the useful/developed questions using (Bonferroni corrected) Mann Whitney U tests.

With respect to knowledge/skills developed during their courses, those in employment claimed to have developed more knowledge about mathematics education and number theory, but otherwise there were no significant between-groups differences.

With respect to the usefulness of the various skills, those in employment believed that computer literacy and team-working were more important to them than those in further study. The reverse was true for: applying mathematics to the real world, thinking in abstract ways about difficult concepts, research skills, written communication, making presentations, independent learning, and many of the areas of mathematical knowledge (algebra, calculus, geometry/topology, differential equations, fluid/solid mechanics, mathematical physics, mathematical modelling and mathematical computing).

4.3 Underdeveloped knowledge/skills

We asked participants to select the five of the knowledge/skills given in Table 1 which they wished they had had the opportunity to develop further during their degree studies. The results of this question are shown, organised by Cluster, in Figure 6.

Perhaps unsurprisingly, the knowledge/skills in Clusters 1 and 3 (those which either were perceived as having been well developed, or which were

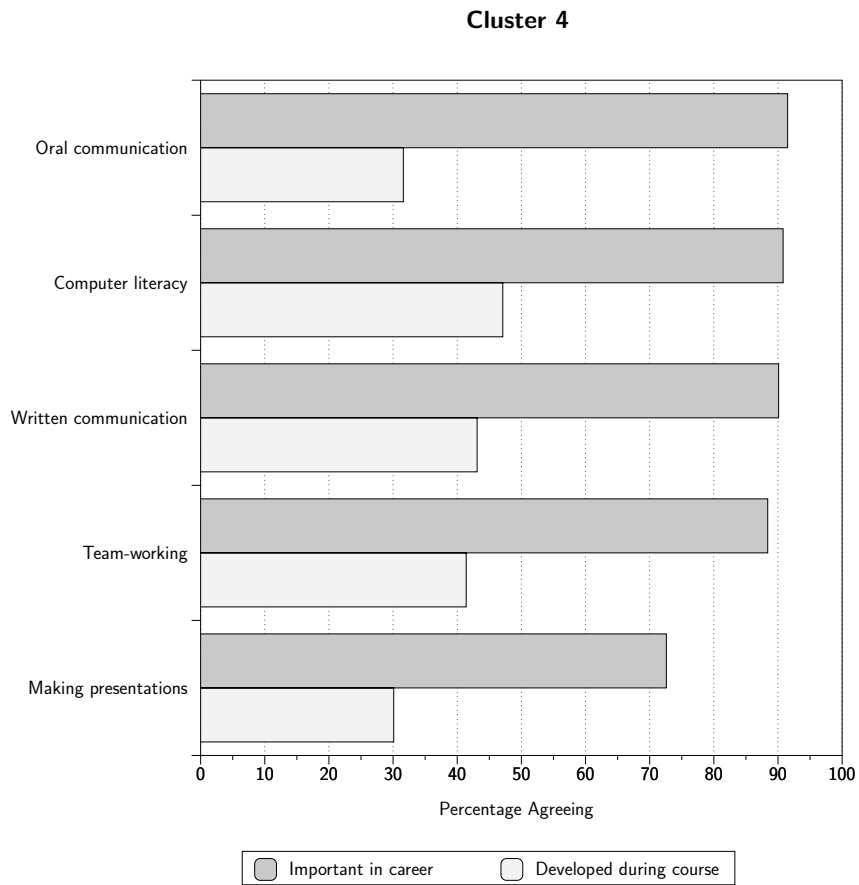


Figure 5: The percentage of participants agreeing that skills/knowledge in Cluster 4 were (a) very/quite important in their career and (b) developed a lot or quite a bit during their course.

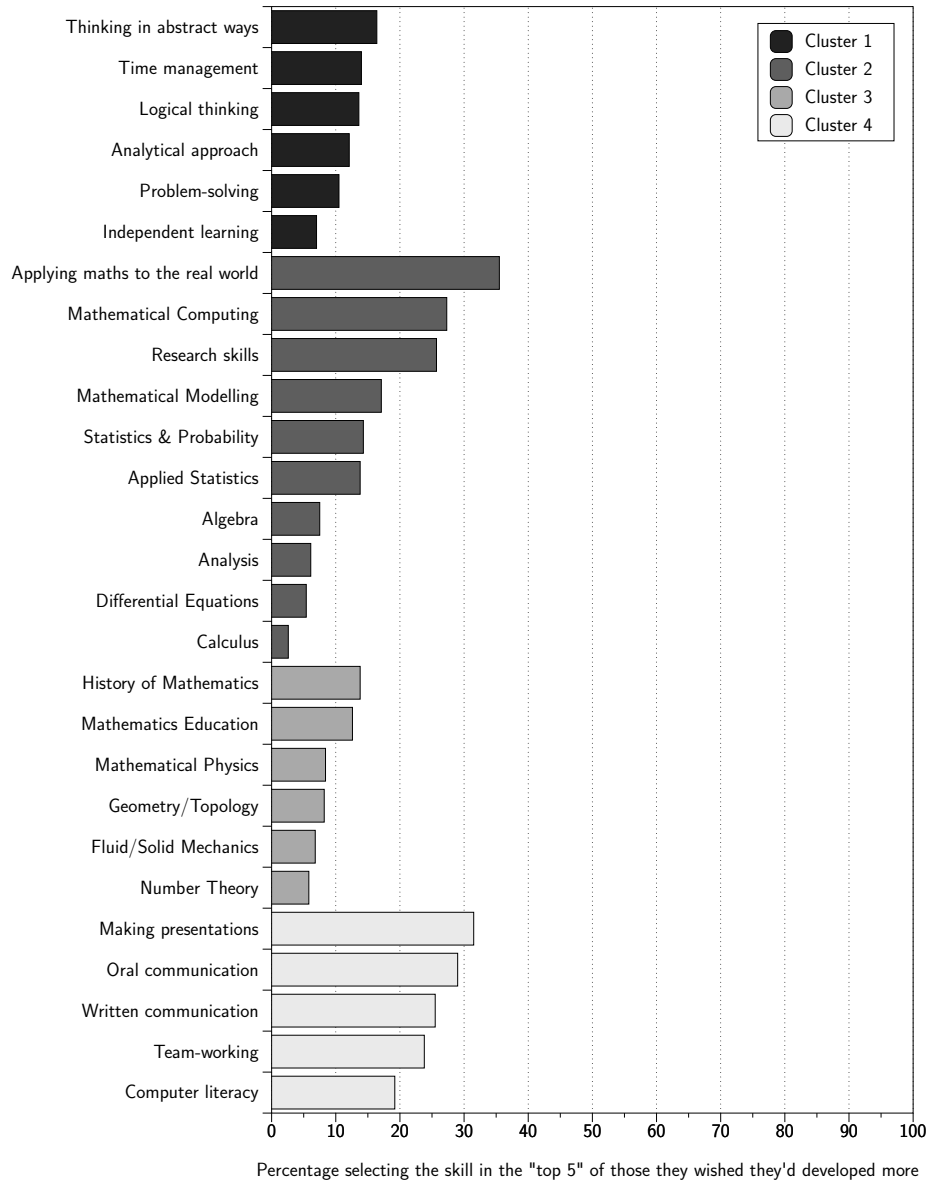


Figure 6: The percentage of participants selecting each area of knowledge/skill among the “top five” of those that they wished they had had the opportunity to develop more during their degree course, by Cluster.

Theme	<i>N</i>
Teaching quality	40
Teaching style	31
Real world applications of mathematics	19
Peer support	16
Group work	15
Opportunity to learn transferable skills	12
Course notes	10
Various other comments	

Table 5: The themes that emerged from an analysis of participants’ free text responses to a question concerning the teaching and delivery of mathematics degrees.

not considered important for graduates’ careers) were not often picked by participants when responding to this question. In contrast, all the generic non-cognitive skills in Cluster 4 scored highly: in particular, participants felt that they would have benefited from the opportunity to develop further their skills of presenting, communication and team-working.

Perhaps more surprising were the scores of the knowledge/skills in Cluster 2. In particular, participants felt that they would have liked to have developed the ability to apply mathematics to the real world to a greater extent than they did. Recall that around 65% of participants felt that this skills was important in their career and around 60% felt it was developed during their course.

4.4 Teaching and delivery

Recall that we asked participants to reflect on the teaching during their degree course:

If you had had the opportunity to influence how your undergraduate degree had been taught in order to improve the learning outcomes e.g. teaching style, mode of delivery, peer tutoring/mentoring, what would you suggest?

There were 242 responses to this question, with many offering suggestions for improvement. We carried out a thematic analysis of their responses which gave rise to the recurring themes shown in Table 5.

Frequently there were contradictory responses. For example, many participants asked for more lectures, more tutorials; others for less lectures and less tutorials. Nevertheless the general message was that participants would have liked to have had more in the way of “teaching” than lecturing, more opportunities for problem solving sessions and more opportunities to discuss mathematics with their lecturers. Participants emphasised the need to see more real world applications of the mathematics they studied, partly so that they would be better prepared to use mathematics in the workplace. The development of generic non-cognitive skills was also emphasised as being important and under developed in university mathematics education. The issue of teaching quality attracted a large number of suggestions, though the message was variable: many reported upon the excellent teaching experience they had had, whereas others clearly felt there was much room for improvement.

4.4.1 Teaching quality

There were forty responses regarding the *quality* of the teaching provided at university. These were distinct from responses about the style of teaching (reported below). These comments showed the greatest amount of variability both within and between institutions. Twelve participants were fulsome in their praise for the quality of the teaching that they experienced:

I was taught fantastically and there was always support there if needed

All the teachers were very involved and prepared to help all students after hours

I think the teaching at the university was amazing and I couldn't think of an area I would change.

The teaching during my degree was excellent.

On the other hand, 24 participants were highly critical of teaching standards:

[Universities should get] rid of lecturers that are well-known to be bad at lecturing

In my opinion a lot of lecturers I had were good at maths but very poor teachers

Several participants referred to the need to impose training requirements on teaching staff:

More rigorous teaching qualifications for lecturers—a large number of lecturers were terrible and a waste of time.

There should be regular departmental assessment of [postgraduate] tutors

Four others noted the variability in their experience, for example:

There is huge variation in the quality of teaching.

Some of the lecturers were really excellent but some were really awful.

Several participants noted that they had experienced foreign lecturers who they found difficult to understand.

4.4.2 Teaching style

As distinct from teaching quality, 31 participants commented upon the style of university teaching and how this might be improved. Many referred to the advantages of the traditional “chalk and talk” method over Powerpoint delivery:

The learning comes in seeing concepts evolve through lines of logic—this means a lecture paced at the speed a lecturer can write can work very well.

The teachers should write as much on the board as possible.

The blackboard/whiteboard forces the lecturer to consider what is being written and leads to more valuable insights being shared than in Powerpoint presentations.

Many wrote about the need to make lectures more interactive and engaging.

I felt I was lectured to and not actively taught.

Lectures are a poor (but necessary evil perhaps) method of conveying the material to large groups of students. They don't cause one to engage with the material

Less mindless copying of notes during lectures.

Make it more interactive. I stopped going to lectures because I got bored by someone just talking at me.

4.4.3 The need for more real world applications

Nineteen responses referred to the need to incorporate more real world applications into undergraduate courses and for teaching staff to have more awareness of mathematical applications outside of the university environment. Typical comments included:

[There should be a] higher emphasis on applying the concepts learnt to problems currently faced in industry

Find lecturers who actually apply mathematics in their jobs, not just sit at uni—their lectures are much more interesting and useful.

My only issue relates to real world experiences as I feel that this is where mathematics students have been let down. There is little if any mention of how to link mathematics to the real world of work.

I would have tried to develop modules where the practicality of mathematics into real world applications would have been more obvious in order to better prepare students for the job market.

4.4.4 Peer support

There were 16 separate references to peer support. With one exception, these referred to the potential value of the university developing a peer support scheme:

If the department had been able to match together people from different year groups who had taken similar combinations of modules. . .

One participant noted how important it is that the university “show that [peer support] is offered”. Whilst one participant thought a formal system was unnecessary “as you often make friends on your course”, another noted that “perhaps we should be allocated to study groups to assist those who don’t naturally find friends on the course and end up working alone.”

4.4.5 Group/team work

There were 15 responses regarding the benefits of including more group-based learning, which, for example, might provide opportunities to present problems and solutions to peers.

[... the course could be improved by] a lot more team work.

One participant noted that the emphasis in his degree on competition and working alone meant that “students missed out on gaining valuable team working skills.” Another added “Team working is one of the most important employability aspects and there is little to none of it in the undergraduate programme.”

4.4.6 The development of generic skills

The need to develop generic skills—those skills which participants believed to be important in the workplace—received 15 mentions. Many stated that there was insufficient opportunity to develop these on undergraduate mathematics courses but that they were essential for the workplace:

I would strongly advise that students desperately need presentation skills, written and oral communication skills which are generally not obtained during their degrees. While maths students leave with extensive maths skills their skills are hard to transfer in the workplace due to inadequate presentation practice.

[There should be more] speaking in front of groups, presentations, organisational skills, soft skills

I think there is a distinct lack of communication skills taught in a maths degree.

4.4.7 Coursework, assessment and feedback

There were twelve references to coursework, assessment and feedback issues. Most suggested that there should be more continuous assessment and less reliance on a final examination. Some suggested the need for more informative feedback:

Ensure there is a decent balance between continuous assessment and examination.

Continuous assessment would have forced me to study harder all the way along.

Explanations of why an answer was wrong can be extremely useful.

Theme	<i>N</i>
Generic skills	41
Real world applications of mathematics	34
Module choices	33
Use of software packages and programming	26
Careers and careers advice	13
Various other comments	

Table 6: The themes that emerged from an analysis of participants’ free text responses to a question concerning how mathematics degrees could be developed.

4.4.8 Course notes

There were ten references to the provision of course notes with participants suggesting that a full set of notes at the start is helpful, that pre-printed notes enable students to spend more time listening and less time copying.

More lecturers to have their notes available for annotation in lectures.

My best lecturer wrote L^AT_EX notes for his courses which displayed tremendous insight and were inspiring to read.

One participant suggested that multiple sources of information should be available whereas sometimes the only source of information was the lecture notes themselves. Another suggested that all notes should be available online so that “that there are not gaps in your learning if you had to miss lectures”. One participant was at odds with the rest, suggesting that print-outs of the notes should not be provided in full at the start of the module.

4.5 Developing undergraduate mathematics degrees

We asked for participants to offer comments that they thought might be useful in informing development of undergraduate mathematics degrees. 182 participants provided comments. We carried out a thematic analysis of their responses which gave rise to the recurring themes shown in Table 6.

4.5.1 Generic skills

Forty one participants referred to the development of generic skills. Those specifically mentioned were team working, oral and written presentations, time management, presenting work to non-mathematicians, research skills, independent study, entrepreneurial skills. The overwhelming majority thought that these were important and ought to be developed more during undergraduate studies:

At [my university] there is an obligation to do a small amount of team working and the occasional presentation, but these skills should be developed FAR more as they will always be needed in the workplace.

On my degree everything was quite abstract—my mathematical understanding has improved by teaching others—having to explain to others by communicating mathematically.

[There should be] more presentations and teamwork—something I struggle with in my current job

Make writing a compulsory component of the degree

Whilst the mathematics taught was interesting, in my experience what was more useful in my degree were the non-maths skills that I learnt

More group work and oral presentations—jobs often look for these skills and I do not have many concrete examples to give.

More opportunities for entrepreneurial development

On the other hand, a small number of participants thought that mathematical material should not be displaced to make way for key skills development:

I wouldn't want maths degrees to lose any academic rigour in trying to cover more soft skills. The rigour is what has developed my most important skill: problem solving, analytical thinking and the tenacity to keep trying until a solution is found.

Some of the skills [listed in Table 1] are relevant to me now, but it would have been inappropriate to dedicate more time to them during the undergraduate course.

4.5.2 Real world applications

Thirty four participants referred to real world applications of mathematics. The need to see such applications came through very strongly in participants' comments, though not unanimously. Many participants asked for more practical uses of mathematics, applying it to real world issues and problems. Some participants referred to getting people in from industry and the need for a greater exposure to the business and professional applications of mathematics.

[There was] little or no application to the real world—an improvement could be constant relating back to practical problems.

Make more relevant to real world situations.

Incorporate industrial case studies

But not all participants agreed:

It is satisfying to learn mathematics for its own sake—don't try and make it more applied.

For me the most worthwhile aspects of the degree were those modules I took because they interested me. Please include the pure modules that may not seem applicable to most careers.

4.5.3 Module choices

Thirty three participants offered suggestions about modules. The majority of these thought that a broader range of modules from which to choose would be an improvement. Many referred to the perceived advantage of being able to take modules in finance and related areas and in statistics. Some were clearly disappointed with the lack of choice and the modules on offer. Some found it difficult to know in advance what a particular module would be about and recommended more work be done to assist students making choices. A small number remarked that learning about the history of mathematics would have been valuable. Some called for more options and others for more compulsory modules.

A wider choice of modules would have been nice.

Keep the variety of modules open so students can choose—you enjoy the work more and get more out of it if you have more control

Make stats compulsory—I chose not to do it and now wish I had.

It would have been nice to study a module that would have helped me directly in my career.

There were not many applied modules—it was largely pure maths but was not advertised that way.

4.5.4 Use of software packages and computer programming

Twenty six participants offered suggestions in respect of training in the use of software. Many emphasised how useful this would be in the workplace. With one exception, they asked for more coverage mentioning particularly Excel, SAS, SPSS, R, C++, Matlab, LaTeX, Fortran, VBA, Java, .Net. Typical comments included:

A degree should include essential programming languages

There should be better integration of computing within courses.

I definitely think we should have been taught to use Excel. It sounds simple—it wouldn't take long to teach, but I realised when I started work how little I knew about it. It is certainly the tool I use most for analysis and I reckon that would be the case for most graduates entering the corporate world.

Teach programming as compulsory throughout

I think it is important to provide students with skills in the most commonly used statistical programmes such as SAS.

4.5.5 Careers advice

Thirteen participants referred to careers with many highlighting the need to offer better careers advice, particularly so that early on in their undergraduate studies they can start thinking about where they might work:

A better understanding of just how mathematicians are employed in as many different fields as possible.

Better industrial links would be nice—I am finding it hard to find employment. . .

More industry links so that undergraduate students have an idea about where they could go after studying. This should happen earlier—we didn't receive any guidance until 3rd year.

There should be third year options available which are directly related to a maths-related career.

Whilst most wanted to see more links between their degree and potential careers that view was not unanimous:

I think it would be a shame if maths degrees became too career focused. Learning maths for its own sake was the most enjoyable part of my university experience.

I think maths degrees are generally great. I think adapting them to suit future jobs is nonsensical. If people want something more applicable to their jobs they should choose a different degree.

4.6 Comparing graduates with incoming undergraduates

As discussed in Section 3, we designed the survey so that the data could be compared with that collected by the More Maths Grads (MMG) project in their survey of incoming undergraduate students (Challis et al., 2009a, 2009b; Robinson et al., 2009; Thomlinson et al., 2009). The MMG surveyed 223 first year undergraduate mathematics students from three diverse institutions before they had taken their first class.

Of particular interest for our purposes was the question in the MMG survey which asked participants to reflect on ten of the areas of knowledge/skill listed in Table 1, and to state to what extent they expected to develop them during their course (like our survey, participants in the MMG study were asked to select either “a lot”, “quite a bit”, “not much”, or “not at all”). We are grateful to the MMG team for making their data available to us for reanalysis.

We compared the median response to these shared items from graduates and incoming undergraduates using Mann Whitney U tests, after Bonferroni correction.¹ Two groups of skill emerged: (1) those where there was no

¹When comparing these data it should be born in mind that the sampling method in the two surveys was rather different: whereas we used an online survey across a very large number of universities, the MMG team used a pen-and-paper questionnaire in three universities. Nevertheless, we believe that comparing these data does yield some useful insights.

significant difference between how well incoming undergraduates expected to develop the skill during their course and how well graduates believed they had developed it, (2) those where the incoming undergraduates expected to develop the skill more than the graduates believed they had.

4.6.1 Group 1

The skills in Group 1—those where the retrospective beliefs of graduates were similar to the predictions of incoming graduates—are shown in Figure 7. The skills in this group were the traditional generic cognitive skills from Cluster 1 (see Section 4.2).

4.6.2 Group 2

The skills in Group 2, shown in Figure 8, represent a mismatch between undergraduates' expectations, and graduates' experiences. They included many of the generic non-cognitive skills from Cluster 4 (see Section 4.2): time management, research skills, oral communication, written communication, computer literacy and making presentations. In each of these cases, incoming undergraduates expected to develop the skill to a greater degree than graduates felt they had.

The other skill in Group 2 concerned the application of mathematics to the real world. Over 90% of incoming undergraduates expected to develop this skill 'a lot' or 'quite a bit' during their studies, whereas only 62% of graduates felt that they had. Recall that this was the skill most often selected when graduates were asked to select those they wish they had had the opportunity to develop more (see Section 4.3).

5 Discussion

We surveyed 428 mathematics graduates from the 2008/9 graduating cohort. We asked participants to reflect on the knowledge/skills they acquired during their degree course, and the knowledge/skills they found useful during their careers. In this discussion we highlight three firm messages of these data, related to (i) generic cognitive skills; (ii) generic non-cognitive skills; and (iii) applicable mathematics.

5.1 Generic cognitive skills

The English philosopher John Locke once asserted that

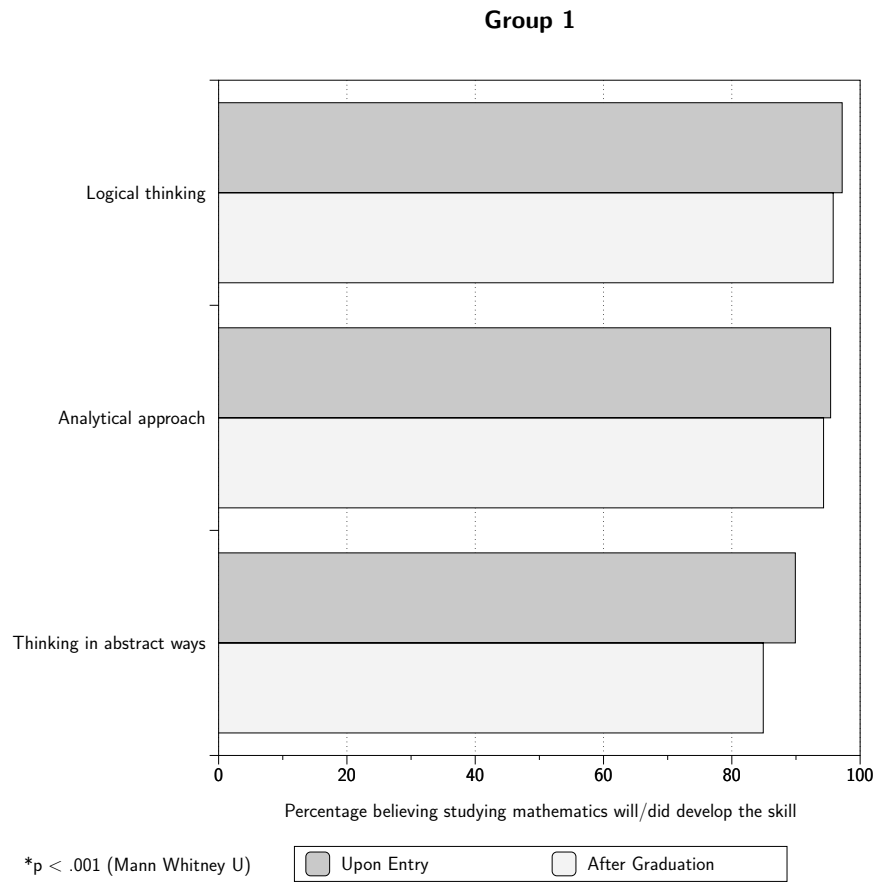


Figure 7: The percentage of (a) incoming undergraduates and (b) graduates stating that skills in Group 1 would be or were developed ‘a lot’ or ‘quite a bit’ during their mathematical study.

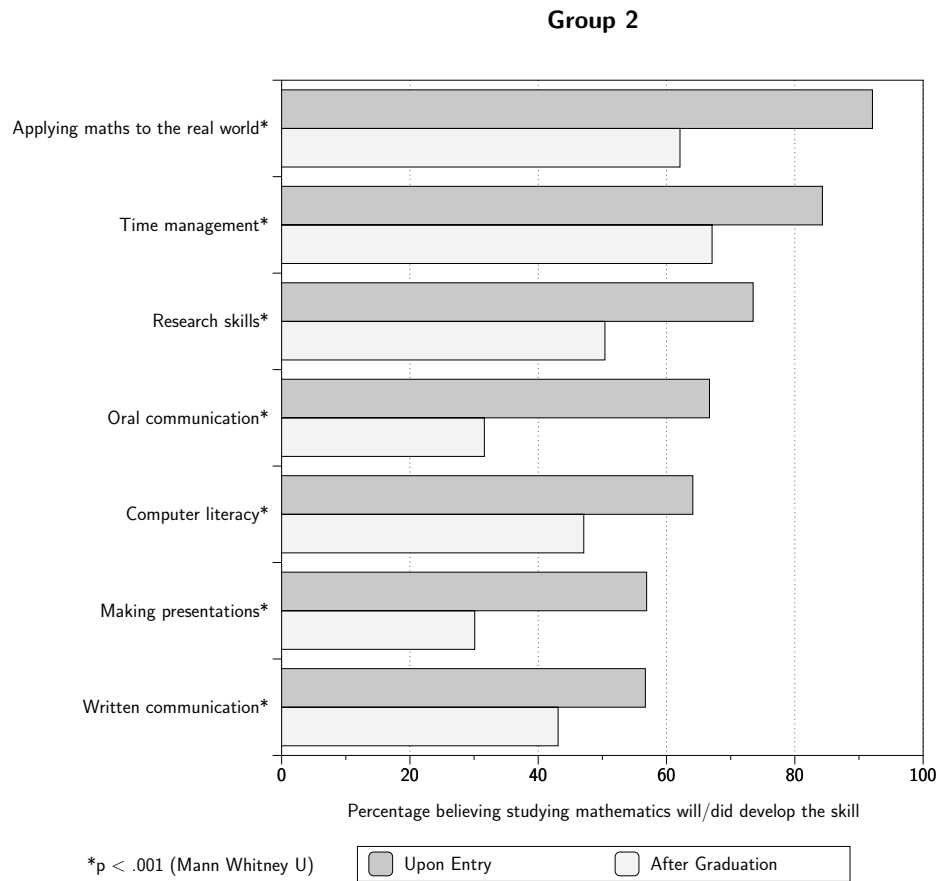


Figure 8: The percentage of (a) incoming undergraduates and (b) graduates stating that skills in Group 2 would be or were developed ‘a lot’ or ‘quite a bit’ during their mathematical study.

[Mathematics] should be taught to all those who have time and opportunity, not so much to make them mathematicians as to make them reasonable creatures (Locke, 1706/1971, p.20)

This belief—that mathematics should be studied because it develops the generic cognitive skills of logical reasoning, critical thinking and problem solving—is known to educational psychologists as the Theory of Formal Discipline. While this theory is controversial in the psychological community (for a review, see Nisbett et al., 1987), we found that mathematics graduates strongly endorse it: overwhelming majorities of our participants believed that studying undergraduate mathematics developed their generic cognitive skills (those in Cluster 1). Furthermore, our participants overwhelmingly believed that such skills are useful in their careers.

5.2 Generic non-cognitive skills

In contrast to generic cognitive skills, we found that few participants believed that their undergraduate study had developed generic non-cognitive skills: those of making presentations, oral and written communication, team working and computer literacy. All these skills were widely seen by our participants as being of substantial importance in the workplace, but were not widely seen as having been developed during mathematical study. Our results are thus consistent with the findings of Wood’s (2010) interview study.

Is this finding a cause for concern for the mathematical community? It is clear that many participants wished that they had had the opportunity to develop their generic non-cognitive skills more in their degree course (in particular, oral communication and making presentations scored strongly on this measure), and that they believe that this would have benefited their career. Consequently it might be worthwhile to consider how these generic non-cognitive skills could be better catered for within existing degree programmes. However, one might challenge this suggestion by asserting, as some of our participants did, that the goal of a mathematics degree should not be adapted to suit future jobs. This position is well illustrated by this remark from one of our participants:

I think adapting [mathematics degrees] to suit future jobs is nonsensical. If people want something more applicable to their jobs they should choose a different degree.

Indeed, one could argue that increasing the focus on generic non-cognitive skills, might inevitably reduce the focus on generic cognitive skills, and therefore be undesirable.

A problem for colleagues who might wish to argue that the focus on generic non-cognitive skills should not be increased in the mathematics curriculum comes from our analysis of the differences between the expectations of incoming undergraduates, and the retrospective opinions of graduates. In particular, there were substantially more incoming undergraduates who expected to develop generic non-cognitive skills, than graduates who believed that they did (see Figure 8). Thus, if mathematics degrees are to continue being structured in a way that does not prioritise the development of generic non-cognitive skills (perhaps for perfectly valid reasons), we suggest that this focus needs to be better explained to incoming undergraduates. Indeed, glancing through undergraduate prospectuses indicates that many departments explicitly do the reverse, and claim that their students *do* develop presentation and communication skills (in an informal analysis of undergraduate prospectus entries for mathematics we found that 11 of our sample of 25 prospectuses explicitly mentioned oral presentations).

5.3 Applying mathematics to the real world

When asked to select which area of knowledge or skill they wished they had had the opportunity to develop more during their mathematical studies, over a third of participants selected “applying mathematics to the real world”. This view was also strongly expressed in the free text responses left by participants.

Learning how to apply mathematics appears to be another area where there is a substantial mismatch between incoming students’ expectations and graduates’ experiences: over 90% of incoming undergraduates expected to develop this skill, whereas only 62% of graduates felt that they had. Again, this mismatch in expectations and experiences may be related to how mathematics degrees are advertised: in our informal survey, 20 of the 26 prospectus entries explicitly mentioned how students would learn how to apply mathematics to real world problems.

6 Conclusion

We surveyed the views of 428 mathematics graduates from the 2008/9 graduating cohort, and asked them to reflect on the knowledge/skills they believed they developed during their mathematical study, and how useful or otherwise such knowledge/skills have been during their subsequent career.

We found a mixed picture. On the one hand, mathematics degrees are perceived as being *extremely* successful at developing very useful generic cog-

nitive skills, such as logical thinking, abstract thinking and problem solving. However, there are a series of generic non-cognitive skills—oral and written communication, presentations, and team-working—which incoming undergraduates expect to develop by studying mathematics, which graduates believe would be useful in their careers, but which graduates do not believe were successfully developed during their studies.

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