Use of Projects in Mathematics

Dissemination from an MSOR Network mini–project survey

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An area of learning that has great potential in developing mathematical skills and wider (graduate) skills is that of incorporating significant project-based activities within the curriculum. Most mathematics courses do include some elements of project work but the extent and depth of the provision in UK Mathematics Honours degrees has not been well documented and the QAA Overview [1] identified issues associated with projects as the '*greatest weakness*'. The mini-project "*Use of Projects in Mathematics*" aimed to identify and share 'good practice' within the UK MSOR community, to clarify associated learning outcomes and also highlight resources available to enable more effective use of project work. To date, activities have included workshops [2, 3, 4] and a comprehensive survey conducted over the summer of 2004. This paper provides a brief overview of the increasing relevance of project activities in a mathematics-major degree for graduates and provides a snapshot of some of the practices and ongoing project activities within the MSOR community. An analysis of a comprehensive survey on project activities based on survey responses from 45 UK Universities identifies the extent and commonality of practices associated with 3-year Bachelor degrees and 4-year Undergraduate masters degrees. Future reconfiguring of any mathematics curriculum should be increasingly aware of a number of external influences and the enhanced expectations of students who, for many, will shortly be more directly funding their studies. Recruitment to mathematics degree courses remains competitive with other Science and Engineering disciplines. Increased access to information on data for students and advisers, including careers advisers and family, to make informed decisions by comparing possible subjects and institutions is now available on the Teaching Quality Information (TQI) website [5]. Detailed official statistical data on student entry, continuation and achievement data is already readily viewable but shortly this will be enhanced with destination data of recent graduates on the HERO website [6]. More integrative learning within mathematics, such as provided by more focussed project-based activities can help enhance students' academic performance, employability and confidence to engage successfully with the challenges of a rapidly changing world and ultimately to greater endorsement of the benefits of taking a mathematic degree course.

1 Project skills in a modern mathematics curriculum

Much of the teaching and learning in an undergraduate mathematics curriculum is provided by traditional lectures and problem workshops and assessment is dominated by examination. Such a format is well embedded as an effective and efficient mechanism to guide and grade students through the general broad groupings of subjects that fall within the category of Mathematics, Statistics and OR. This emphasis provides well for knowledge content and many subject-specific skills that have traditionally underpinned a mathematics curriculum. This is further identified in the MSOR Benchmarking Document [7] which formulates that most mathematics programmes have both '*theory-based*' and '*practice-based*' elements. Project activities are perceived as a major tool for skills development and consolidation and application of theory within '*practice-based*' elements of programmes.

An increasing emphasis from Government is on the employability and career progression of graduates following the Treasury Report (Roberts Report) [8] and also concerns over the Strategic Science Provision in Universities [9] and this is echoed in a recent Government response [10]. It is widely recognised that STEM (Science, Technology, Engineering and Mathematics) graduates play

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an important role in meeting the demands of employers for skilled personnel to ensure the UK can maintain its competitive edge in a global market. Such an expectation is incorporated in the framework for higher education qualifications issued by the QAA [11] in which it is recognised that:

> *"An Honours graduate will have developed an understanding of a complex body of knowledge, some of it at the current boundaries of an academic discipline. Through this, the graduate will have developed analytic techniques and problem-solving skills that can be employed in many types of employment. The graduate will be able to evaluate evidence, arguments and assumptions, to reach sound judgements, and to communicate effectively."*

To address all the above goals, alongside selection and attainment of knowledge and understanding of mathematics syllabus topics, ever more consideration is required to ensure that students connect subject content, skills and self-development to achieve deeper level understanding and confidence in applying mathematics to tackle real-world situations. Mathematics is recognised as a subject that has potential for graduate entry in a wide range of employment or postgraduate study and embraced in the MSOR Benchmark Statement [7] - *'All such employers know that MSOR graduates possess knowledge and skills that will enable them to make a contribution that is beyond the capabilities of those without a background in MSOR'.* This emphasis identifies an increasing expectation of extending learning outcomes for mathematics degree students on mathematical and graduate skills, many of which can be delivered effectively through integrative activities.

Relevant descriptors for UK HE qualifications have recently been defined by the National Qualifications Framework and articulated by the QAA [11]. Within the framework of an Honours level degree, explicit reference to project work, but also identification of a variety of outcomes that can be acquired readily from project related activities is made:

***Typically, holders of the qualification will be able to*:**

a) apply the methods and techniques that they have learned to review, consolidate, extend and apply their knowledge and understanding, and to initiate and carry out projects;
b) critically evaluate arguments, assumptions, abstract concepts and data (that may be incomplete), to make judgements, and to frame appropriate questions to achieve a solution - or identify a range of solutions - to a problem;
c) communicate information, ideas, problems, and solutions to both specialist and non-specialist audiences;
d) the qualities and transferable skills necessary for employment.

The position of 4-year Undergraduate Masters (MMath/MSci) remains under development following the signing of the Bologna Declaration and subsequent discussion on a European Framework for HE Qualifications is included in the Bergen Communiqué [12]. Three Bologna cycles are included, bachelor's, master's and doctoral, with qualification descriptors identified by the QAA as comparable with the UK's framework for HE. The Bergen seminar however noted agreement to the continued existence of '*integrated one-tier programmes leading to Master's courses*' and that the next two years is seen as a period of consolidation prior to the next ministerial conference (London 2007). Addressing the issue of the future of the MMath the Council of Mathematical Sciences (CMS) has provided a briefing paper [13] that includes the identification of separate modules designated at master's level, for the fourth year. A project is suggested as one of these fourth year modules, weighted as much as 25% of the year.

2 Integrative Learning

Currently there are a number of ongoing initiatives at HEFCE and Institutional levels which may influence the future requirements of a mathematics curriculum but may be well matched by development of project-based activities integrated in future curricula. Currently, most university courses are engaged in '*programme specifications*' to provide '*clear and explicit information for students so that they can make informed choices about their studies and the levels they are aiming to achieve*' [15]. Individual Higher Education Institutions (HEIs) have consequently been recommended to identify the intended outcomes of programmes in terms of:

- The knowledge and understanding that a student will be expecting to have on completion;
- Key skills: the use of information technology and learning how to learn;
- Cognitive skills, such as an understanding of methodologies or ability in critical analysis;
- Subject specific skills, such as laboratory skills.

Within this format the provision of lecture-based teaching, learning and assessment provides a strong element to the attainment of knowledge but more limited contributions to other elements.

The MSOR Workshop [2] was aimed at sharing practice for the implementation, support and assessment of final-year projects and first-hand examples were provided by invited practitioners. In a plenary session the increased advantages of using project activities were perceived as:

- adds variety to student learning experience;
- promotes practice in the application of mathematics (e.g. modelling, data handling);
- provides wider assessment possibilities;
- develops research and scholarship skills;
- develops generic and wider subject-specific 'graduate skills'.

It was further recognised that within an enriched curriculum project activities are not restricted to final year but should be staged throughout the programme and may involve:

- project assignments to widen skills development within appropriate modules;
- group projects to enhance learning and develop teamworking skills;
- individual projects identifying scholarship or review;
- research informed individual projects.

Although the Workshop focus was on final year project activities, the consensus viewpoint of the participants was that such project work should build upon previous experiences from small-scale project activities integrated within earlier years. Examples cited included modelling, data-handling, numerical methods (including use of computer algebra) either as individual or group project exercises.

3 Use of Projects – a national survey

A survey on project activities was sent during the Summer of 2004 to all 67 UK HE Institutions identified as offering single honours mathematics and mathematics major courses with 2004 entry. Respondents were asked to consider 'projects' as a reasonably substantial element in the third or possibly fourth year of study including stand-alone projects, group projects or projects within Research/Communication/Skills modules.

3.1 Responses

The survey attracted a direct response from 45 institutions offering 48 replies that included multiple responses from some institutions where more than one distinct type of course is offered. A response rate of 67% was attained giving a sufficiently high response and across all types of Institutions to indicate a representative snapshot of current provision and practice in undergraduate projects. A good balance and distribution of responses was also received on a regional basis, as identified in Table 1, which is particularly encouraging as HE provision in terms of funding, QAA review and other Institutional and teaching and learning initiatives typically have a regional element.

Country groupings	England	Northern Ireland	Scotland	Wales	Total
No. of responses	36	1	5	3	45
% response rate	68%	100%	63%	67%	67%

Table 1 Survey responses based on UK Regions

The survey was email based and consisted of three main topic areas.

i) The first referred to Bachelors degree courses. 96% of respondent courses include final year projects or project-based activities, with approximately 40% of these using optional and 55% using compulsory projects. The number of students participating with project activities averaged around 25 students irrespective of whether the provision is compulsory or optional; suggesting that generally large cohort courses tend to make project provision optional whilst smaller cohort tends to make the provision compulsory. This is borne out from survey responses that indicate where projects are optional, on average around 20% of students commonly choose to participate. There are however some significant exceptions where compulsory projects are managed for over 100 students. Projects mostly account for one eighth (10 responses out of 20) or one sixth (7 responses) of the final year. Less commonly the proportion is closer to one-third of the final year (3 responses).

ii) The second question related specifically to Undergraduate Masters courses and all but one of 23 responses were from pre-1992 Institutions, reflecting the predominance of MMath to this sector. From the survey responses all but two of these courses use compulsory final year projects, and these correspond to Institutions with a large final year student cohort. Projects in Undergraduate Masters degrees commonly account for one quarter (10 out of 22 responses) to one third (8 responses) of the credits for the year. Most also offer an optional third year project (6 responses) or a compulsory third year projects (6 responses) with the remaining Institutions providing students with no experience of project activities prior to their fourth year.

iii) The third question concerned the types of project activities used and in particular the availability and balance between individual/group activities and of

providing students with experience of research/ scholarship. A survey response from around 44 institutions has enabled a clear framework to be established. Some 86% of respondent courses use research informed individual projects; 93% use individual scholarship, investigation or review projects. Also 78% of respondents have individual project activities that included modelling or skills-based modules in their course and 59% make use of group project activities.

Details and analysis of the results are provided in the following sections giving details of the survey outcomes.

3.2 Classifying universities

It is recognised that within the University sector the formation and development of Institutions and also their mission statements and emphasis between teaching, learning, research and wider skills, vary but there are some well developed self-classification groupings. To identify the representative nature of the Survey the responses from the different groupings have been considered and evaluated. Methods of classification of universities included rankings systems, ratings systems and recognised groupings are provided in a previous section. Standard classifications of HEIs are given by the pre- and post-1992 Universities. Further divisions is given by considering pre-1992 Universities that belong to the Russell Group and from the 1994 Group and CMU Group as subsets of the post-1992 Universities.

Groupings	Pre 1992 Group	Post 1992 Group	Russell Group	1994 Group	CMU Group
No. of responses	33	12	14	8	5
% response rate	69%	63%	78%	75%	56%

Table 2 Survey responses based on University classification groupings

The disposition of responses shown in Table 2 suggests that the Survey findings correspond to a balanced representation across the UK HEI sector. Overall the proportion between the Pre-1992 Group and Post-1992 Group is closely balanced. The largest subgroup of responses were obtained from Universities in the Russell Group with a 78% return; a similar percentage return was obtained from the 1994 Group but due to smaller membership of targeted courses the actual number was relatively small. Survey group data has consequently been analysed primarily for the largest groupings of Pre- and Post-1992 Groups and the Russell Group as the largest subgroup of responses; this approach still includes all responses and mitigates abnormal data biasing smaller data sets.

The Survey questionnaire was designed to encourage a good response rate, and to obtain base information on the type and level of project activity. Correspondingly the questionnaire was e-mailed based, short and relatively straightforward to answer. A further important element was that the email was targeted, where possible, to an appropriate staff member within each Institution. Such staff were selected with a known interest in project-based activities, such as responses to previous project initiatives or with a School/Department responsibility for course or project administration identified from each course website.

3.3 Survey results

i) BSc/BA Degree - Final Year projects

a) *Are final year projects or project-based activities part of your Course?*

47 respondents answered this question

	no		yes-optional		yes-compulsory	
Total	2	(4%)	19	(40%)	26	(55%)
Pre-1992	2	(6%)	17	(50%)	15	(44%)
Post-1992	0	(0%)	2	(15%)	11	(85%)
Russell	2	(13%)	9	(56%)	5	(31%)

These responses indicate that project-based activities are generally well embedded in the curriculum with 96% of HEIs making these a part of their courses. There is a marked distinction between courses derived from post-1992 Institutions with 85% requiring students to undertake compulsory project activities compared with pre-1992 HEIs where 44% give students no choice. The provision of a compulsory project element is under a third in Russell Group Universities surveyed and two (13%) had no project provision in the final year.

b) *How many students (typically) are involved each year in projects; if optional - the percentage of the cohort?*

35 respondents answered this question, 17 gave a percentage for optional modules.

Number of students:

	Optional		Compulsory	
	Mean	Median	Mean	Median
Total	23	20	35	23
Pre-1992 Group	21	13	46	30
Post-1992	50	(1 response)	25	20
Russell	34	25	71	55

Percentages of students selecting optional projects:

	Mean	Median
Total	19%	15%
Pre-1992 Group	19%	15%
Post-1992	-	-
Russell	25%	18%

Some insight into the extent of project provision in terms of student numbers is given by the survey returns with several HEIs dealing with a compulsory project provision for large numbers of students (2 with over 100 students). Post-1992 HEIs have a high incidence of compulsory projects within their curriculum but returns suggest the course numbers are modest with an average number of around 20-25 students. Russell Group universities have on average higher intakes with those with a compulsory project provision typically around 55 students. Courses where projects are optional are confined to Pre-1992 Universities where typically 15% of students choose a project option with a slightly higher uptake in the Russell subgroup of around a quarter of the cohort.

c) *What is the credit rating of these projects or project activities (% of year credit total)?*

41 respondents answered this question but not all provided full information. The credit rating used by Universities are almost universally based on 120 credits in a year but a few are different and conversion adds a small amount of dispersion to the results however the results are generally consistent between number of credits and the percentage. In responses received, half of the respondents did not give an actual credit rating but only a percentage or proportion and correspondingly only the percentages are presented in the group analysis.

19 responses gave a credit rating and 37 responses a percentage of year credit.

	Credit rating		% of year credit total	
	Mean	Median	Mean	Median
Total	24	20	17%	16.67%
Pre 1992 Group			16%	15%
Post 1992			19%	16.67%
Russell			16%	15%

Almost universal consensus across the mathematics provision identify project modules take about one-eighth to one-sixth of the final year although a small number of institutions allow or require students to take project activities covering up to one-third of the final year.

ii) MMath/MSci Degree (Undergraduate Masters)

a) *Are final year projects or project-based activities part of your Course?*

26 respondents answered this question.

no	yes-optional	yes-compulsory
1	1	24

MMath degree courses are predominantly grouped within pre-1992 Universities which is reflected in 25 replies from this group (13 from the Russell Group) and only two from post-1992 group. Overwhelmingly the inclusion of a final year project is an integral part of the curriculum for an MMath degree however this was not compulsory at two universities. The institutions with an optional projects have some of the largest intake of students for an undergraduate masters and this is seen as a restricting factor in their curriculum design.

b) *How many students (typically) are involved in fourth-year in projects; if optional the percentage of the cohort?*

23 respondents answered this question; 22 responses were from pre-1992 Universities (10 from Russell Group)

	Mean	Median
Total	17	10
Pre-1992	12	7
Russell Group	25	18

The survey highlights the number of students involved with MMath projects varies widely, from a cohort of a few students in some HEIs to several with at least 40 students. The uptake of MMath in Russell Group Universities is highest with around 20 students per year and about 10 students per year is typical of other pre-1992 Universities. At the only university providing an optional project, about 10% of the cohort was involved in projects.

c) *What is the credit rating of these projects or project activities (% of year total)?*

Limited responses were provided regarding credit ratings with respondents preferring to identify the percentage of the year, however a fair consensus of 22 responses in this category provides the following uniform pattern:

	Mean	Median
Total	27%	25%
Pre 1992 Group	27%	25%
Russell	26%	25%

Individual responses gave project assessment at 10 universities a credit rating of a maximum of 33% within the final year and 8 with a credit weighting of 25%. Remaining HEIs weighted this as a sixth or and eighth of the year.

d) *Are third-year projects or project-based activities part of your Course?*

21 respondents answered this question.

no	yes-optional	yes-compulsory
9	6	6

This question aims to identify the level of direct project experience students may have received in scheduled

project activities prior to undertaking a final year MMath project. A third of HEIs provide prior exposure to project activities, a third does not and a third make an option available to students in the previous academic year.

e) *How many students (typically) are involved in third-year in projects; if optional the percentage of the cohort?*
Due to the limited number of project activities in question 2d, correspondingly restricted responses were provided for this question with only 7 entries. Of the 4 Institutions who required student to undertake compulsory projects 3 involved less than 6 students but the fourth had a cohort of 40 students. Of the three institutions that identified optional provision take-up of projects averaged 20%.

f) *What is the credit rating of these projects or project activities (% of year total)?*
Only 9 responses were relevant in this section, which were grouped to provide data relating to the percentage of these activities. The mean project activity involved 15% of the year with a median provision being 12.5%.

iii) Types of Project activities
Please indicate which of the following types of project activities are included in your Course as a substantive module:

a) *Research informed individual projects*
44 respondents answered this question.

	Yes	No
Total	38 (86%)	6 (14%)
Post -1992	9 (82%)	2 (18%)
Pre-1992	29 (88%)	4 (12%)
Russell	14 (100%)	0 (0%)

b) *Individual projects identifying scholarship, review or investigation*
44 respondents answered this question.

	Yes	No
Total	41 (93%)	3 (7%)
Post -1992	10 (91%)	1 (9%)
Pre-1992	31 (94%)	2 (6%)
Russell	12 (92%)	1 (8%)

c) *Individual project activities included in Modelling or Skills - based modules*
41 respondents answered this question.

	Yes	No
Total	32 (78%)	9 (22%)
Post –1992	9 (82%)	2 (18%)
Pre-1992	23 (77%)	7 (23%)
Russell	11 (85%)	2 (15%)

d) *Group project activities*
44 respondents answered this question.

	Yes	No
Total	26 (59%)	18 (41%)
Post –1992	8 (67%)	4 (33%)
Pre-1992	18 (56%)	14 (44%)
Russell	9 (69%)	4 (31%)

Responses indicate that individual projects are an undoubted area of the mathematics curricula which is informed by research activity. At the more research-intensive Russell Group universities, not unexpectedly, all those with project provisions, students could select projects that were research informed but this was a general feature of 86% of HEIs. Projects enabling students to learn from further scholarship, review or investigation on an individual basis was a feature at 93% of universities. It is recognised that 'smaller-scale' individual projects can be a developmental feature of more wider-based teaching such as within modelling of skills-based modules and these were evident in 78% of returns; in some cases such modules provide suitable training and experience for students prior to undertaking a substantial individual project. Responses to a final question on the provision of Group project activities identify this area is not a feature that is yet well embedded in MSOR with over 40% not including such activities.

Conclusions and future work

The position of declining numbers of young people continuing to study mathematics post-16 in the UK is evaluated in-depth within the 2004 Report '*Making Mathematics Count*' (Smith Report [16]) and in particular draws attention to the following possible factors:

- the failure of the curriculum to excite and provide appropriate motivation
- the lack of awareness of the importance of mathematical skills for future career options and advancement.

Closer study reveals these comments are a specific reflection on the current mathematics provision 14-19 but are equally applicable at degree level if the supply of graduates with high-level mathematics capabilities is to be maintained. A key component part of a modern mathematics curriculum is the provision of project-based activities which can be used to extend the understanding and application of knowledge gained by more lecture-based methods. Undertaking such individual or group activities, students can more readily engage in-depth learning on wider areas of their personal interest. They can also acquire important problem-

solving skills needed to be successful in future careers in business, industry or research. Inclusion of student attainment of wider skills is also now increasingly expected as an outcome of UK Honours degrees and for comparison with European graduate qualifications.

The survey identified that 55% of Bachelor degree course in Mathematics include final year projects or project-based activities as a compulsory element and another 40% include this as an optional element. Unfortunately, where a project is optional, typically only 20% of students choose to participate and this possibly reflects the additional demands on students in taking such activities compared to other learning methods. This may also reflect the lack of awareness students may have in the importance of gaining additional mathematical skills. As might be expected, the provision of compulsory projects was significantly higher at 86% for Undergraduate Masters courses, where the heritage of Postgraduate Masters degree includes a substantial dissertation. A further practical consideration is that most final year provisions for MMath/MSci have smaller cohorts of students compared to the corresponding BSc/BA courses and are concentrated in the pre-1992 university sector. Project provision for MMath/MSci courses are almost universally substantial and taking about 25% of the final year, and commensurate with CMS proposals, but prior preparation and training in terms of prior projects or project-based activities remains limited.

The survey indicates that in over 90% of HEIs students could engage in individual projects identifying scholarship, review or investigation; research-informed individual projects were available in 86% of HEIs. Other forms of project activities were explored in the form of modelling or skills based modules and replies indicate that in over 80% of such modules individual project activities are required. Group project activities are less well embedded in the curriculum with only around 60% of courses providing subsequent team-working experiences to graduates.

The universal provision of substantial project activities remains an underdeveloped area of the undergraduate mathematics curriculum. Such activities have the potential of promoting individual study, research and employability skills in students and of highlighting the versatility of mathematics graduates. This is particularly relevant at a time when a number of external influences are indicating that degree specifications should embrace an extended range of subject specific and wider skills. A measure of the success of graduates following a mathematics course will increasingly be observed and project-based experiences and competencies will enhance their:

- employability upon graduation
- success at post-graduate study
- promotion in their early career positions.

Within the mathematics community project activities are widely identified as a valuable component of a mathematics degree programme but there exists widespread concerns over implementation issues. Problems range from provision and selection of projects, management and organisation of project activities, training in skills, assessment and plagiarism, feedback, etc. Some of these aspects have been discussed within the framework of the University Mathematics Teaching Conference which has usefully identified significant experience and consensus of 'good practice' exists within the community. Further, corresponding workshop reports [3, 4] have provided directed advice and, most helpfully, details of project implementation at a number of Institutions as possible templates. This approach is in concert with the unanimous view at the MSOR Workshop '*Sharing Project Practice*' [2] which advocated that increased use of project-based activities would be enhanced by greater dissemination of practices and materials. This has, in part, been started with the creation of a website facility [17] but is an item for further development within the community in collaboration with the HE Academy.

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