Review of Engineering Mathematics curriculum at UCD in light of qualitative changes in secondary-school mathematics education in Ireland

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INTRODUCTION

In recent years, the development of problem-based learning (PBL) has been an important trend in education, often within inherently technical subjects such as mathematics and engineering [1]. This has major implications on the scope of curriculum design [2, 3], notably in that the underlying thrust of the hierarchical and taxonomical architecture is altered substantially. Although PBL has been discussed at third-level education (see, e.g. ref. [1]), a recent emerging trend has been the development of PBL in second-level education. With this in mind, in view of the recent introduction (circa 2010-2012) of the 'Project Mathematics' PBL-based syllabus for the Irish school-leaving ('Leaving Certificate') examinations (and subsequent two-year 'lag' before this cohort of students has reached university in Ireland and elsewhere), it has become necessary to recast, revise and alter the timing of the engineering-mathematics curriculum at University College Dublin. This paper discusses these necessary changes and curriculum redesign to accommodate students who have been taught mathematics at secondary school in Ireland in a qualitatively different way to more traditional, teacher-led approaches in which there is a strong emphasis on 'hierarchical' structuring of learning. 'Project Mathematics' is based on a problem-based learning approach.

As shall be discussed, at UCD, changes have resulted in a time-compression and redesign in mathematical coverage in first year in two modules, with 'knock-on' effects on syllabi in subsequent years. Early, informal indications suggest that the redesign has been quite effective. This may be of interest to other institutions in light of plans in other countries, *e.g.*, Great Britain, to embrace PBL in secondary-school syllabi in the coming years.

1 PROJECT MATHEMATICS

1.1 General Background

The Irish National Council for Curriculum and Assessment (NCCA) undertook a review of secondary-school mathematics in 2005, in terms of a fundamental appraisal of the effectiveness of existing syllabi as agents for outcomes-focussed learning. Some previous studies had emphasised concerns [4, 5], chief of which were: (i) the over-reliance on a very didactic and procedural pedagogy with little emphasis on broader problem-solving skills; (ii) the elevation of 'abstraction' as a core principle; (iii) middling ranking in successive and recent OECD PISA tests in the early- to mid-2000's, and (iv) a lower than desired proportion of students opting to sit the higher-level Leaving-Certificate examination, and their performance on it. Other concerns highlighted included an over-use of 'rote learning' and a lack of deeper knowledge of fundamental mathematical concepts by students. Naturally, this less than desirable situation, and consequential effects on third-level mathematics education and performance were key concerns, and this had been pointed out more informally for some years amidst Irish third-level circles, and also wider industry and employers in Ireland.

1.2 Adoption of Project Mathematics approach

Bearing the factors discussed in 1.1 in mind, this led the NCCA, after a consultation process in 2005-06 to propose the 'Project Maths' approach in 2007. Broadly, this calls for greater engagement with PBL to buttress more procedural nous and skills, with the teacher as the focus of curriculum development. This required a substantial change in teaching style as well as wholesale, qualitative changes to the curriculum *per se*. It was considered appropriate to introduce the changes as both junior and senior cycles in second-level education simultaneously, *i.e.*, in both first and fifth year at the respective outset of the Junior and Leaving Certificate cycles (roughly at ages 12 and 15-16), so as to provide continuity for the cohorts of students to which it was applied initially on a trial basis during 2008-10. A 'cooperative' philosophy underpins Project Maths, in that it seeks to: (i) stress the connections between mathematical concepts, (ii) encourage pupils to find multiple solutions, (iii) fostering multiple representations of ideas, and (iv) exploring mathematics in 'real-life' scenarios. Indeed, Whicker et al. [6] and Yamarick [7] have concluded that cooperative approaches help to support higher levels of achievement by pupils. Skills development has been an important goal of Project Maths, and critical and creative thinking, as well as information processing and teamwork, have been key in this area. Project Maths was adopted across the entire Irish secondary-school sector during circa 2010-2012 at both junior- and senior-cycle levels, so this clearly has ramifications for the curriculum design of third-level mathematics education. The latter is the main topic of this paper and is discussed below. Although beyond the gambit of the present paper's discussion, it must be borne in mind that not all of the preliminary evidence of Project Maths' effectiveness in realising its stated goals at second-level points to an unqualified success; rather, the experience has been somewhat mixed at this level [8].

2 REDESIGN OF ENGINEERING MATHEMATICS AT UCD

2.1 Previous Curriculum Structure

With slight variations within each of the major disciplines of Engineering, the broad thrust of common mathematics courses has followed the general anatomy outlined below. This has been based on students taking four mathematics courses in first year (each with approximately 24 lectures) on (i) sets, functions, continuity, differentiation, curves, etc, (ii) introductory linear algebra and eigen-analysis, (iii) integration and ordinary differential equations, and (iv) series, partial differentiation, and Lagrange multipliers. Building upon this pure-mathematics foundation, in second year were a further three courses on (i) further linear algrebra, including some numerical applications, (ii) multi-variable and vector calculus, and (iii) probability and statistics. In terms of beginning to consider more applied aspects of mathematics, as well as pure mathematics, third-year courses focussed on (i) Laplace, Fourier and complex-number analysis, (ii) integral calculus (e.g., Divergence and Stokes' therorems and applications), and (iii) differential equations (e.g., coupled systems, partial differential equations, solution methods and engineering examples).

2.2 Redesign for Project Mathematics

At present, UCD Engineering favours a more 'traditional', lecturer-led approach towards mathematics teaching and learning, in which there is a strong hierarchical taxonomy. With this in mind, it has been necessary to redesign the structure of the curriculum on a staged basis throughout each year, so as not to disturb particular years, or cohorts, of students studying the previous and new curricula for that particular year of study. Below, we outline these changes; in particular, the lesser focus on integration, vectors and basics of matrices at Leaving Certificate level under the Project Maths approach necessitated these changes. Additional tutorials were felt to be beneficial for the learning process, given their more interactive nature, *ipso facto*, vis-à-vis more 'hierarchical'–style lectures.

The main changes have resulted in a time-compression and redesign in mathematical coverage in first year in two modules (each 36 lectures and 12 tutorials) whose current syllabi were revised especially in terms of calculus, vectors and linear algebra to 'mesh' in a more seamless way with the 'Project Mathematics' syllabus. In terms of resultant, 'knock-on' effects on syllabi in subsequent years, the primary changes were in a second-year course on multi-variable calculus, with the placement of other material, such as vector calculus, Fourier analysis and applications to physical problems, placed in a third-year course. The rationale for the changes was largely such that 'lacunae' at Leaving Certificate level in key, procedural aspects of pure mathematics essential for engineering (such as integration, vectors and basics of matrices) needs to be accommodated, along with extra tutorials for students accustomed to PBL-style approaches in their earlier mathematics education. Below, we describe in some more detail the new architecture of the engineering mathematics courses.

In first year, there are two courses, on introductory calculus and linear algebra, which did require relatively extensive curriculum re-design. The calculus course covers limits, differentiation, Transcendental functions, Indefinite and definite integrals, series (geometric, Taylor, etc) and ordinary differential equations. The linear algebra course covers number bases, complex numbers, partial fractions, solving systems of linear equations, matrices, basic eigen-analysis, vectors and three-dimensional geometry, linear independence and similarity transformations.

There are a further two courses in second year, on multi-variable calculus and probability and statistics. The primary changes were to the second-year course on multi-variable calculus: given the more restricted knowledge of students coming from the new first-year background (*vide supra*), a new course includes some, but not all, of the material. A second course on multi-variable calculus was introduced at third-year level. There were more limited changes to the course on probability and statistics, primarily to reflect the importance of practical, 'hands-on' experience with statistical packages as a desideratum, reflecting in some sense the nature and philosophy of Project Maths at school level.

2.3 Appraisal of Changes

Overall, with the very recent implementation of this new engineering-mathematics syllabus, early, informal indications suggest that the redesign has been quite effective in terms of appropriate 'mapping' onto the students' school-level mathematics background and abilities, helping with a good transition to university-level mathematics education in Engineering. Feedback from students in the latter stages of their degree courses indicate that their mathematics learning in the earlier stage of their time at UCD, following on from Project Maths at school level, leads them reasonably well equipped to tackle problems and material in other engineering-, numerical- and science-oriented courses, assignments and projects.

3 SUMMARY AND ACKNOWLEDGMENTS

This paper has discussed changes made in the engineering mathematics curriculum at UCD in light of the introduction of problem-based learning approaches in school-level mathematics education. Particular thanks are afforded to Mark Lynch, Paul Curran, Michael Bruen, William O'Connor and Paul Fanning.

REFERENCES

[1] Savin-Baden, M. (2008), 'Problem-based Learning in Electronic Engineering: Locating legends or Promising problems?', *Int. J. Elect. Eng. Educ.*, Vol. 45, pp. 96-109.

[2] Fraser, S.; Bosanquet, A. (2006), 'The curriculum? That's just a unit outline, isn't it?', *Studies in Higher Educ.*, Vol. 31, pp. 269-284.

[3] Diamond, R.M. (2003), 'Designing and Assessing Courses and Curricula: A Practical Guide', Jossey-Bass, San Francisco.

[4] Smyth, E.; Hannan, C. (2002) 'Who Chooses Science? Subject Take-up in Second-Level Schools.' Liffey Press/ESRI, Dublin

[5] Smyth, E.; McCoy, S.; Darmody, M. (2004). 'Moving Up: The experiences of First-Year Students in Post-Primary Education', Liffey Press/ESRI, Dublin

[6] Whicker, K.M.; Bol, L.; Nunnery, J.A. (1997) 'Cooperative learning in the secondary mathematics classroom', *J. Educ. Research*, Vol. 91, pp 42-48.

[7] Yamarik, S. (2007) 'Does cooperative learning improve student learning outcomes?', J.

Economic Educ., Vol. 38, pp 259-277.

[8] Jeffes, J.; Jones, E.; Wilson, M.; Lamont, E.; Straw, S.; Wheater, R.; Dawson, A. (2013) 'Research into the impact of Project Maths on student achievement, learning and motivation: final report', NFER, Slough