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TEACHING IN CONTEXT: INTEGRATING MATHEMATICAL THINKING AND PERSONAL DEVELOPMENT PLANNING INTO THE CURRICULUM FOR PART-TIME, DISTANCE-LEARNING ENGINEERING STUDENTS

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Abstract

This paper describes changes to the way mathematics is taught to engineering students at The Open University, moving away from *service teaching* via generic mathematics modules to incorporating mathematics teaching into the core engineering curriculum. Mathematics is taught in the context of engineering with the aim of reducing the emphasis on derivations and mathematical proofs and putting greater emphasis on understanding basic concepts and being able to create useful models. Mathematical methods are taught and practised, then extended and applied to different engineering contexts as students' progress through modules, in order to develop students' mathematical thinking and build confidence. Professional development planning has also been embedded into engineering teaching for improved context and relevance and a more integrated approach to assessment has been taken across the whole qualification.

Introduction

The Open University (OU), based in Milton Keynes with six national and regional centres across England, Scotland, Wales and Northern Ireland, is one of the largest universities in the UK with over 170,000 registered students. This total includes approximately 4500 students currently studying towards an undergraduate Bachelor of Engineering (BEng (Hons)), Bachelor of Engineering Top-up (BEng (Hons)), Master of Engineering (MEng), or Engineering Foundation Degree/Diploma of HE (FDEng/DipHE).

The OU has an open access policy and, with very few exceptions, there are no formal academic entry requirements. Some students on the engineering programme join with no previous educational qualifications (PEQs), though often with extensive practical vocational experience, whilst others may bring transferred credit from Higher National Certificate or Diploma qualifications. The majority of our engineering students are in full-time engineering-related employment.

As a result of higher education funding changes for England in 2012, the OU changed its student registrations from a module-based to a qualification-based system to enable access to loans for part-time study. This change resulted in more prescriptive and structured routes through the engineering degrees as well as simpler identification of students registered for particular

qualifications. This enabled the performance of students on individual modules making up the qualifications to be interrogated more easily at a qualification level and problems identified. The changes were reported by Organ and Morris (2012).

We identified that engineering students were performing poorly on two, 30 CATS, compulsory mathematics modules and consequently failing to complete their first year (equivalent full-time) of study successfully. Anecdotal evidence and feedback from students suggested that engineering students would benefit from greater connections between mathematics principles and relevant engineering topics and techniques.

Following an evidence-based approach we proposed a restructuring of the engineering qualifications to incorporate mathematics teaching in an engineering context. The new structures incorporate revised study patterns allowing students to pace their studies more effectively alongside their work and family commitments. Teaching is delivered primarily through a mixture of print and online media distance learning with some face-to-face or online group tutorials and laboratory based residential schools. Students are supported in their studies by Associate Lecturers who typically work with groups of 20 students and provide individual support alongside the tutorial programme. The curriculum has been designed to satisfy the academic requirements of the United Kingdom's Engineering Council's professional registration framework (2014).

Mathematics skills, personal and professional development planning, practical laboratory based residential schools, and wider skills are all integrated into broader modules that provide context and relevance to students while they are studying engineering topics. We have also taken an integrated approach to assessment, developing an assessment strategy for each stage of the qualification rather than on a module-by-module basis.

Curriculum changes

Mathematics in an engineering context

The wide range of student abilities in mathematics skills and preparedness on entry to engineering degrees has been recognised as problematic for a long time (Mustoe, 2002; Cardella, 2008; Alpers et al., 2013). The problem is exacerbated at the Open University as students come from a wide range of educational backgrounds and may not have studied mathematics formally for many years; many students also exhibit low confidence in dealing with mathematics. Approaches to help students on entry to conventional HEIs (Perkin & Bamforth, 2011), such as additional lectures or drop-in support sessions, are impractical in a distance-learning setting. We know that the majority of our engineering students are in full-time employment and frequently combine study with work and family commitments and have finite time for study. Strategies that give students additional workload to strengthen their mathematical skills are unlikely to succeed in the context of the OU.

From October 2012 to February 2016 our engineering students were required to study 2 x 30 CATS modules of mathematics at FHEQ (Framework for Higher Education Qualifications)

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level 4 (SCQF – Scottish Credit and Qualifications Framework level 7) from a choice of 3 x 30 CATS modules. The two modules included a compulsory 30 CATS module in Essential Mathematics. The second mathematics module choice would either further support open access students requiring more introductory practice in mathematics or alternatively provide a more challenging mathematics module for those students who were intending to study further engineering mathematics at a higher level. The compulsory Essential Mathematics module was designed primarily to satisfy the requirements of the mathematics teaching programme and students on mathematics qualifications and was available to study either from October to June or from February to September each year. The proportion of BEng(Hons) students gaining credit on Essential Mathematics in the period from October 2012 to February 2016 varied from 34 to 51 percent.

Although there was an upward trend in the percentage of BEng (Hons) students gaining credit over the period it was, nevertheless, at an unacceptably low level and having a detrimental impact on progression, as students were required to either re-sit the end of module examination or retake the module at the next opportunity. Many students failed again on re-sitting the examination, were unable to progress, and were lost from the programme.

From October 2016 students no longer study mathematics modules in isolation as we have integrated mathematics teaching into the core engineering modules, ensuring that it is taught in context.

Much of the base content has been adapted from the existing mathematics modules but the emphasis has been on *mathematical thinking* – that is, understanding basic concepts, creating useful models and recognising reasonable solutions to engineering problems. We also encourage students to experiment and to interrogate units to aid their understanding of relationships between physical quantities and check their results. We are encouraging students to define a problem and then to identify what information they would need to solve it, which we hope will discourage students from learning mathematics by rote and consequently being unable to apply it to unfamiliar situations. A *learning spiral* approach has been taken where engineering content places mathematics skills in context; these skills are taught, practised and applied, and are then revisited, extended and applied further as students' progress through the curriculum.

Personal development planning (PDP) and skills development

It cannot be assumed that on entry to The Open University students automatically have the skills required for successful study at degree level since approximately one-third enter the university with no *A level* (or equivalent) qualifications. Even those with conventional university entry qualifications frequently lack the skills required for distance-learning or have been away from formal education for many years.

We have incorporated PDP and professional skills into our engineering qualifications for many years to ensure our graduates are well prepared if they wish to apply for Incorporated of

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Chartered Engineer status, and to enhance their employability. Our qualifications align with the requirements of the UK Standard for Professional Engineering Competence (UK-SPEC). Prior to 2012, students were required to study 2 x 15 CATS specialist PDP modules at level 4 and level 6. Student loan funding changes in England in 2012 necessitated combining learning content into larger credit modules and this provided the opportunity for us to integrate PDP into other engineering modules. PDP was integrated with technical content, engineering professions' case studies and compulsory practical engineering residential schools to produce 2 x 30 CATS modules – one at level 4 (SCQF level 7) and one at level 5 (SCQF level 8). PDP was continued into an individual engineering project module at level 6 (SCQF level 9).

We have subsequently taken the approach of integrating PDP and study skills into other core engineering modules, enabling key skills such as communication, presentation skills and report writing to be studied alongside relevant engineering concepts. Students maintain an online log of their learning activities which forms the basis of a portfolio of evidence which can be transferred between modules and used if they subsequently apply for chartered engineer status with a professional institution after graduation.

Study patterns

Prior to October 2012 engineering students could study up to 120 CATS credits in an academic year, although the majority chose to limit their study to 60 CATS credits a year. However, the times at which different modules were available meant that approximately half of new entrants to the engineering programme were studying 2 x 30 CATS modules concurrently (from October to June) resulting in high intensity study, and then having a break until the following October. This study pattern meant that students often had conflicting assessment cut-off dates and were frequently unable to get their assignments submitted on time. Students adopting an alternative study pattern where they started their second module in February were more likely to be successful, but the study intensity was not evenly spread across the year.

We have now amended study patterns so that students study the first 2 x 30 CATS modules of their engineering qualification consecutively over a 12-month period, with the first module, Engineering: origins, methods, context (T192), studied from October to March and the second, Engineering: frameworks, analysis, production (T193), studied from April to September. Students would then go on to study a more mathematically intense 30 CATS module, Engineering: techniques, maths, applications (T194), from October to June in their second year of part-time study, completing stage 1 study with 30 CATS Engineering: professions, practice and skills I (T176) which incorporates a residential week of laboratory-based study. Our aim is to ensure that students do not have conflicting assessment dates, are able to concentrate on one module at a time at this early stage of study, and are able to utilise knowledge and skills acquired in the first module to successfully study the second module. Sequenced skills development plays an important role alongside knowledge attainment as students' progress through the modules.

A schematic of the modules studied at level 4 for the BEng (Hons) and MEng is given in Figure 1.

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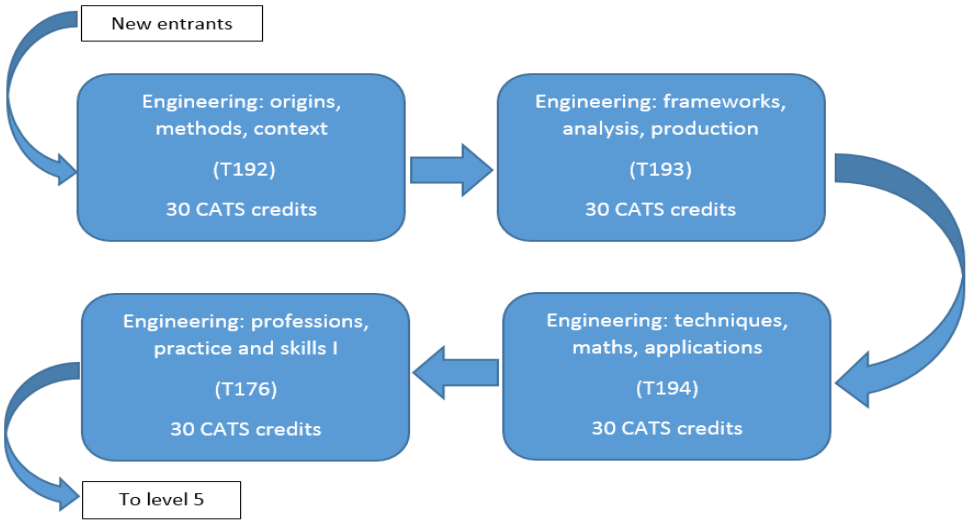

Figure 1. Schematic of study order for new entrants to OU engineering qualifications from October 2016

Assessment

We have taken a qualification-based approach to assessment, ensuring that assessment tasks build in difficulty as students' progress through each module and build in type as they progress through the qualification stage. Students are required to complete formative activities which have been designed to feed into summative assessment at regular intervals and, if they complete these activities at the appropriate time, assignments should be straight-forward and not the last minute rush often experienced by part-time learners. Pacing of assessment activities in this way also benefits reflective skills development as adequate time remains close to an assessment deadline for students to review their work, complete self-assessment reflective activity, and finalise their assessment submission. Student self-assessment of intended learning outcomes attainment is also built in to assignments, ensuring good student engagement with the intended learning outcomes.

Students are continuously assessed through tutor-marked assignments (TMAs) and interactive computer-marked assignments (iCMAs) combined with end-of-module assignments and unseen examinations where appropriate.

Practice quizzes are incorporated into most weeks' study for the duration of the first three modules and the time taken to do them is accounted for in the overall study time. These quizzes enable students to have multiple attempts at particular mathematical problems, with feedback given for incorrect answers. More formal mathematical assessment at level 4 takes the form of iCMAs developed at the OU and outlined by Jordan (2014). Students are allowed 3 attempts at each question, with feedback for incorrect attempts suggesting where the student has made mistakes and referring them to appropriate module material as necessary. Each question has several *variants* ensuring that each student gets a different set of questions from their peers,

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mitigating against plagiarism. Student can repeat the iCMAs as many times as they wish up to the cut-off date, emphasising their role in promoting learning rather than simply testing.

iCMAs and practice quizzes are combined with tutor-marked assignments to ensure that all the intended learning outcomes are assessed appropriately.

Initial results and student feedback

At the time of writing, the first cohort of engineering students that entered the University in October 2016 has completed the first two modules, Engineering: origins, methods, context (T192) and Engineering: frameworks, analysis, production (T193) and is part way through study of Engineering: techniques, maths, applications (T194).

Analysis of this cohort show that 75% of students have completed and passed the first module (T192), with 91% of these progressing immediately to study the second module, T193, in April 2017. The pass rate for these students on T193 was 73% and of these 81% have progressed immediately to T194, in October 2017. Pass and progression rates of this order are very encouraging on open-access qualifications where students are often encountering distance learning for the first time. The pass rate for engineering students of 75% on T192 is significantly higher than that achieved by the previous entry module prior to October 2016, which varied from 65-68%. We will not be able to make meaningful comparisons with previous cohorts until all study at level 4 (SCQF level 7) has been completed, but we are confident that greater numbers of students will progress successfully to level 5 (SCQF level 8) and beyond.

Integration of mathematics teaching with engineering content has been welcomed by students as two quotations from a recent student survey illustrate

> *I am particularly pleased with how the mathematical content is taught. It makes a lot more sense to develop maths alongside the core subjects. It helped me to understand how the maths is relevant and applied. I have previously studied pure maths in isolation, but did not enjoy it to the same extent. Using maths within an engineering context is a big improvement it helps to animate the subject.*

> *I can happily say that I have learned more about maths and calculus in these last two months of studying than I have in about two years of school and 6th form.*

Another student, reflecting on their learning on the first two modules stated

> *Having studied the T193 module as a follow-on from T192 you begin to realise that the journey is not just about the end qualification but the way it develops you as a person. It has been a tremendous effort to get to this stage but the time has flown by. The sense of achievement at the end is priceless.*

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Associate Lecturers (ALs) have also broadly welcomed the changes to the curriculum and a more formal consultation with ALs and evaluation of their experiences is planned. The comment below from an experienced AL is typical of the feedback we have received to date.

> *I found the way the maths was taught was very good. Introducing new maths concepts in each chapter and in the context of the engineering topics helped the students to understand not just how to do it but also why they do it and how it applies to real situations. Feedback from my student group was mostly very positive about the maths and I found they had a better grasp early on of the basics.*

Conclusions and future plans

The ethos and methodology applied to level 4 of the engineering qualifications will be continued as higher levels of the curriculum are redeveloped. Based on evidence to date, and our experience so far through the redesign of the engineering curriculum, we will continue to work towards qualifications that are more integrated in nature. Engineering context is key for part-time distance learners, particularly when they are already employed in a sector relating to their chosen academic discipline. However, we have taken care when choosing examples, case studies and images not to make assumptions about students' prior experience and to make the teaching material relevant to a diverse student group. The integration of mathematics teaching with core engineering content is proving more popular with students and their tutors, particularly at the early stages of the qualifications. We will also continue the integration of personal and professional development planning in the context of technical engineering content - all towards enhancing student academic success and employability skills.

Although it is too early to make any firm conclusions about the success of the reconfiguration of the undergraduate engineering curriculum at The Open University, we are encouraged by early indicators and the increased student retention rate on the first two modules of the revised qualifications. Feedback from students and Associate Lecturers has been positive and pass and progression rates have both improved since the introduction of the new modules. Further projects are in place to track the performance of students through the new modules as they progress through their qualification (this is not trivial, since students can pause or resume their studies, or switch between qualifications, at any point), to learn from the experiences of the ALs delivering the modules to students, and to gain a better understanding of the particular motivations and aspirations of our female students, for whom progression rates are currently lower than for men.

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