Introduction

Engineering can be defined as the “application of mathematics and sciences to the building and design of projects for the use of society” (Flegg et al., 2012:1). The need for the development of quantitative skills (QS) in engineering is clearly articulated in the engineering competency standards: *1.2 Concept understanding of the mathematics, numerical analysis, statistics and computer and information sciences which underpin the technology domain* (Engineers Australia, 2013). Quantitative skills are defined as “the ability to apply mathematical and statistical thinking and reasoning in context” (Rylands, Simbag, Matthews, Coady and Belward, 2013:834).

Underlying this need for QS has been a decrease not only in Australia but internationally in the mathematics background of first-year university students (Barrington, 2013; Croft and Ward, 2001; Hunt and Lawson, 1996). There has been a decrease in the number of students studying intermediate and advanced mathematics since 1995 (Barrington, 2013; Brown 2009). The reasons for this decline are complex but in part may be due to cultural attitudes, the lack of pre-requisites for entry into Science, Technology, Engineering and Mathematics (STEM) courses at many universities, and higher scaling of the lower level mathematics for university entrance scores, at least in NSW (Australian Mathematical Sciences Institute, 2015). Consequently, many students are mathematically underprepared when enrolling in STEM-based courses. Universities need to know what mathematical background the students have and be able to provide the appropriate level of support to help them develop the relevant QS; and need clear curriculum maps to show the development of the QS once at university. Numerous engineering curriculum maps have been developed and conducted for graduate attributes and key competencies, for example Gluga et al. (2012), Lawson et al. (2013), and Morsi et al. (2007). However, key graduate and first-year QS have not been mapped for engineering courses.

Before determining if the QS of students are developing throughout their course, the key skills need to be defined and mapped across the course. In this study at the University of New England, the mapping of QS taught, practiced and assessed in the first year of a number of STEM courses was undertaken. This paper aims to explain how the first-year QS were mapped for one course, the Bachelor of Engineering Technology (BET), and describe the resulting curriculum changes.

Background

At the University of New England, a program, which aimed to improve the first-year student experience and encourage inter-disciplinary and inter-school collaboration across the university, was implemented in 2013-14. A First Year Teaching and Learning Network Coordinator (Coordinator) was appointed in each school. The authors were the Coordinators for the two schools that teach the sciences and engineering. In this role, they collaborated on joint projects as they identified issues that were common to both schools. For example, BET students are administered from the School of Environmental and Rural Science, which includes the engineering units, while the School of Science and Technology provides the first-year service units in mathematics, physics and chemistry core to that course. Both on campus and distance students are taught in a blended learning environment, and both attend on-campus intensive schools of 3-5 days. Blended learning is defined as “the organic interaction of thoughtfully selected and complementary face-to-face and online approaches and technologies” (Garrison and Vaughan, 2008:148).

In deciding the focus of their collaboration in terms of their Coordinator positions, the authors reviewed the first-year experience literature and ran a scoping project to identify current issues for the Schools. Wilkes and Burton (2015), as part of the national project funded by the Australian Government Office for Learning and Teaching, assessed students’ mathematical skills when entering university and found many students at this university lacked key QS. Through a First Year Experience Survey for teaching staff and students, the diversity of students' background mathematical skills was seen as a key issue (unpublished data). This led to the development of the QS mapping project, which extended the work of Mathews et al. (2013).

Methods

Establishing the conversation

In a national project examining curriculum mapping of graduate attributes across four disciplines including engineering, Lawson et al. (2013:44) found the main challenge was *"getting staff engaged with the process and helping them not to see it as an extra burden on their time".* As the perceived motivation for the curriculum mapping can impact on staff engagement with the process (Lawson et al. 2011), the team clearly communicated how and why QS should be mapped. To gain staff buy-in the team established a conversation about the importance of QS development for students and used a bottom-up approach, where feedback from academics was included in the project development and implementation.

A QS workshop was held, attended by 35 academics representing 15 disciplines from Science, Technology, Engineering and Mathematics (STEM). Staff were divided into mixed discipline groups, with at least one mathematician or statistician in each group. Staff worked through questions that asked them to consider issues that may impact on student development of QS and identify issues for the applied or pure science disciplines that may differ from those identified by staff in the mathematics discipline. This workshop laid the foundations for the project by establishing an atmosphere of honesty, openness and collaboration.

To maintain the momentum behind the project Dr Kelly Mathews from the University of Queensland was invited to give a seminar. She explained the issues relating to the development of QS across Australia that she had found in the national OLT project on QS. This highlighted that the issues academics face at the University of New England are shared across Australia and, in some cases, internationally. This motivated the staff to engage in the mapping process as they realised action was required to enhance the development of students' QS.

Mapping the QS

Curriculum maps are used in the curriculum development process because they allow ready identification of how skills are developed, any overlap or gaps in the curriculum, and provide an opportunity for reflection and discourse (Biggs, 2003; Fallows and Steven, 2000). Mapping the QS was divided into five phases from the establishment of the list of key graduate QS, through the mapping process and finishing with action plan workshops (Figure 1). Although the aim was to map the QS for first year, it was first necessary to define the QS at the graduate level (Phase 1; see Reid and Wilkes, 2015, for further detail).

As a result of cross-disciplinary discussions in the first mapping session, it became apparent that different levels of attainment would be expected in different disciplines and courses. Initially two levels were proposed by the project team. Should students be able to identify and follow basic analysis in a familiar context; or be able to compare and contrast, select, justify and apply an appropriate analysis in an unfamiliar context at an advanced level? But when discussing this with the engineering discipline it was clear that a third, intermediate level was required, to comply with the competencies stated in the Engineers Australia accreditation documentation (Engineers Australia, 2013). This can be summarised as: Should students be able to identify and follow basic analysis in an unfamiliar context? The full descriptors for the three levels are given in Reid and Wilkes (2015).

Lawson et al. (2011) indicated three major elements are required for curriculum mapping including; a mapping ‘tool’, a ‘process’ of how the tool will be implemented, and a clear ‘purpose’ justifying the need for the map. These elements were included in Phase 2, which involved the design and programming of an electronic mapping tool using Visual Basic (VB) in Microsoft Excel. This tool allowed the rapid assimilation of unit maps into course maps. Unit coordinators for 24 first-year units mapped the week(s) they taught, practiced and assessed each QS in their unit. This process included all first-year units in the BET, resulting in a complete map of the first year of the course. The resulting unit maps were verified by the unit coordinators and incorporated into course maps in Phase 3. The course maps were verified by the researchers and the course coordinators. Any errors or omissions were corrected and the final maps produced.

Phase	Tasks and outputs
1	Draft QS list from literature → Identified Graduate QS for B.Science, but realised refinement required → Identified 2 ‘levels of attainment’ and revised QS list → Identified Graduate QS for BET but revised ‘levels of attainment’ to 3 → Final QS list and three levels of attainment → Identified Graduate QS for 11 other courses
2	Development and testing of QS unit mapping tool → Unit coordinators input data for when QS taught, practiced and assessed (TPA) → Unit maps produced and verified by unit coordinators
3	Unit maps combined to create course maps of QS TPA → Maps verified by researchers → Maps verified by course and unit coordinators
4	24 STEM academics interviewed → Identify issues related to the development of students’ QS → Issues summarised and first-year mathematics curriculum review began
5	Change implementation action plan workshops held with course and first-year unit coorindators → Increased awareness of QS issues and curriculum changes including major curriculum review of first-year mathematics

Figure 1: Summary of the key tasks and outcomes of the QS mapping project (adapted from Reid and Wilkes, 2015)

Phase 4 included interviews with 24 unit coordinators to identify any issues students have developing QS in their unit. Staff were asked to reflect on issues that arose due to differences in the teaching modes for on campus and distance students. These issues were summarised and presented at a cross-school forum on QS for permanent and casual staff.

Phase 5 included action plan workshops for each of the key courses. At these workshops the relevant course coordinator, unit coordinators and other interested staff teaching into the course developed plans to implement changes identified as necessary to enhance the development of students’ QS. As a result of the forums and workshops there was an increased awareness of QS issues across both schools. This cross-disciplinary information was fed into a major curriculum review of first-year mathematics.

Results

The maps allowed a wealth of information to be easily viewed and interpreted. For example, Figure 2 provides an excerpt of a unit map for a unit in the BET showing in which week the QS 11 and 12 was taught (T), practised (P) and assessed (A) and at what level . Once the unit maps had been verified course maps were created for each course. Below is an excerpt from part of the BET course map showing when (week) and where (unit) one of the QS (number 4) was taught, practiced and assessed (Figure 3).

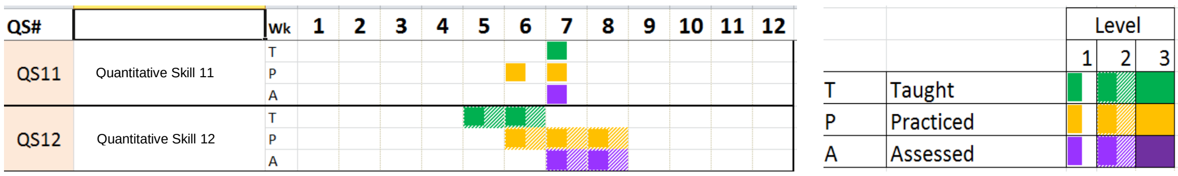

Figure 2: Excerpt of a unit map. Key given on right.

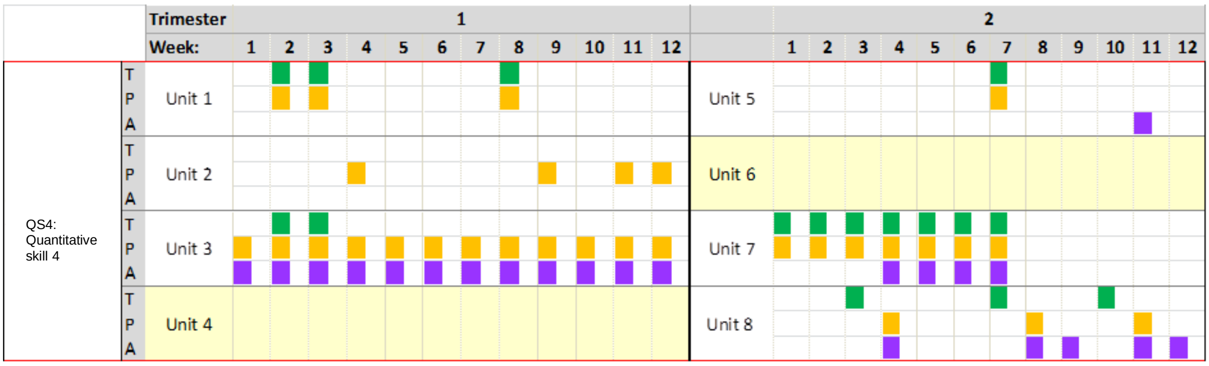

Figure 3: Excerpt of course map of QS in core FY units. Key as per Figure 2.

Discussion

Strategies for change

Previous curriculum mapping projects have shown that academics can find the process threatening as it can be interpreted as a course-cutting exercise, or a criticism of their teaching materials; and seen as a labour-intensive process (Oliver, 2010). It was therefore very important in the QS project to ensure academic staff felt ownership of the process and did not feel threatened. This was achieved by using an ‘inclusive’ approach based on academics collaborating (Lawson et al., 2013).

Establishing the conversation surrounding QS was an important first step in the change process. Acknowledgement was made that staff may have differing views of how QS should be taught and differing knowledge of the current curriculum. As mathematics disciplines usually teach the engineering students their prerequisite mathematics (and statistics) the engineering disciplines often have little knowledge of the content that is being taught, practiced and assessed (Flegg et al., 2012). The QS mapping project aimed to address this.

As the proposal was to create action plans from the QS maps, which required leadership to engage academics with the process, the 7 strategies for culture change by Kotter and Cohen (2002) were followed. These strategies were used by Lawson et al. (2013) for mapping graduate attributes. Initially, ‘getting the vision right’ was achieved through establishing the conversation and gaining a shared meaning of QS. ‘Executive support’ was gained from both Heads of School, thus giving gravity to the project. A ‘team was built’, consisting of the authors and both Deputy Heads of School; and champions were identified in each discipline. ‘Rewards and recognition’ included convincing staff of the mapping process’ usefulness, effectiveness, benefits and potential for curriculum change. As staff had input they felt included and thus felt ‘empowerment’. Also through ‘communications for buy-in’ the mapping process was sold as a simple process that would yield a wealth of information, and formal and informal feedback was sought from the academics.

Mapping QS for BET

'Closing the loop' is seen as an important final step in curriculum mapping and includes continuous curriculum improvement (Lawson et al., 2013). Phases 1–4 of the QS mapping process catalysed the staff to reflect on the first-year curriculum, and the resultant maps fed into a formal review of the mathematics curriculum. The first draft of the new mathematics curriculum was mapped, and new course plans were created and used in the Phase 5 BET action plan workshop.

The Phase 5 BET action plan workshop was attended by the course coordinator, first-year unit coordinators, and all engineering teaching staff. The team went through each of the QS and a vigorous discussion focussed on issues such as: when and how some of the skills were taught and what changes would enhance the development of students' QS. The main discussion points and outcomes are summarised in the following.

Assumed knowledge

As stated previously the mathematical background of students entering university has decreased over the past two decades. The University of New England is a distance education provider, with a large proportion of mature-aged students. As a consequence many students left school 10 or more years ago, and so assuming students have a current working knowledge of key QS is problematic. Admittance into the BET assumes NSW HSC Mathematics (2 unit) and recommends Chemistry, Physics and/or Biology, depending on the major. Students without this background knowledge are directed to complete foundation units before beginning their course. However, as this is not mandatory, some students may enrol in the BET without this background knowledge. An example of how this issue is addressed is described below.

Although metric conversion is treated as assumed knowledge, the approach taken to ensure that students have developed this QS differed among three semester 1 units in the BET. Staff in one unit found they needed to go over this skill to ensure students correctly performed calculations in practical sessions. In contrast, in another unit the material was not explicitly taught but links were made to external online resources via the Learning Management System (LMS, Moodle) allowing students to independently access the material as required. In another unit it was an assumed skill and no additional support was provided.

Consistency of terms between disciplines

There are substantial differences in the use of mathematical terminology and notation between engineering and mathematics academics, compounding the issue of students not seeing the relevance of mathematics units in engineering courses (Flegg et al., 2012). During the QS mapping sessions and at the BET action plan workshop discussion regarding consistency of terminology spontaneously occurred.

A vigorous discussion centred on significant figures and how to measure and report the accuracy of results. One of the academics wanted to develop a consistent message in all first-year units, or at least develop an understanding of how different disciplines use decimal places versus significant figures, calculate errors, and make error adjustments. This discussion led to one academic sharing their resources on accuracy, and an email conversation continued for a number of weeks after the meeting. The staff teaching first-year BET students now have a clear understanding of how error is calculated in the different disciplines and can better answer student's questions.

Some QS were interpreted differently across disciplines and, depending on the mathematical background of the cohort taking the unit, the delivery method differed. For example, optimisation was taught in the mathematics units in terms of the standard application of maxima and minima, and linked to linear algebra. In contrast, in the sustainability unit, which does not have mathematics as a prerequisite or co-requisite, the concept of optimisation in resource economics was taught diagrammatically.

Timing

As the units at the University of New England are blended with face to face and online recourses, some of the issues with timing of QS being taught, practiced and assessed can be alleviated with online resources. The course maps allowed staff to see that, for full-time on campus students who satisfactorily completed all semester 1 units, most QS that were not assumed knowledge were taught before being practiced and assessed. Complex numbers was the exception. A robust discussion occurred regarding when complex numbers should be taught. The course map showed that complex numbers were previously taught in mathematics at the end of semester 1 and were required in physics in early semester 2. But with the new draft mathematics curriculum complex numbers would not be taught until later in semester 2. Therefore the physics staff agreed to include a tutorial and supplementary online resources on complex numbers before they were used in the practical.

This discussion raised another issue: In what order should distance students be advised to enrol in first-year units? In the recommended BET course plan distance students are recommended to enrol in mathematics and physics in their first year. For those who are mature age, studying part-time and may not have studied for a number of years it is recommended that they take the mathematics and sustainability units in their first year, and chemistry and physics in their second year.

Application of QS

First-year service units are taught in a wide range of course programs. A lack of motivation and interest is a common problem when teaching engineering students mathematics, as they often cannot see the usefulness and application in their discipline (Flegg, Mallet and Lupton, 2012; Konstantinou-Katzi et al. 2013). Mathematics units are more likely to be effective where there is regular consultation between mathematics and engineering staff on curriculum development (Henderson and Broadbridge, 2007). As each QS was discussed at the BET action plan workshop, examples of how they were used in the first year and later years were discussed. For example, the engineering staff were able to give examples of how integration and trigonometry are used in fluid mechanics, hydrology, concrete technology, and surveying, thus giving the academics teaching service units contextual examples to be used when teaching engineering students.

Flegg et al. (2012) argue that engineering mathematics curricula should be designed as a tool in the study of other subjects, and a tool for dealing with real-world problems. To address this matter a proposal has been made to the Head of School for Science and Technology for tutorial assistance in service units to be provided by engineering postgraduates and adjunct staff. This was successfully trialled in 2014 in a first-year mathematics unit, and grades improved on previous years.

Where to next?

The BET course coordinator has requested the mapping project be expanded to map the QS for the whole course. The ability to easily see how and when each QS is being taught, practised and assessed has allowed staff to view any issues in the development of QS in first year.

In engineering courses mathematics is a prerequisite to more advanced mathematics units and engineering units; and a lack of conceptual understanding in mathematics may hinder their understanding of future units (Kashefi et al., 2013). “Many engineering students have limited understanding of fundamental mathematical concepts and often move to the more advanced mathematics courses while lacking important basic skills” (Konstantinou-Katzi et al., 2013:333). To increase students’ motivation towards prerequisite skills Morsi et al. (2007)

presented concept maps of mechanical, chemical and computer engineering course programs to students in a seminar. They found all students felt more motivated to perform better because they now understood how classes tied together. By explicitly communicating which concepts were a prerequisite in subsequent units all students felt they would be more motivated to learn those concepts. Therefore, the team intend to present the first-year QS course maps and graduate QS skills for each course to the students.

In addition to embedded engineering tutors, there is a need to review the context of assessments. Flegg et al. (2012) state that engineering and mathematics disciplines need to work closely together to ensure mathematical rigour is maintained and that assessments are focussed on real-world problems. There is currently an open channel of dialogue between the engineering and mathematics academics; and this is an opportune time to propose contextualised assessments.

Benchmarking is essential to the maintenance of standards, and it is proposed that a national workshop be held to define the QS required for each engineering discipline for the BET and Bachelor of Engineering. This will be held at the 2015 AAEE conference. Institutions could then map where these QS are taught, practiced and assessed in first year, through to graduation. This would allow true benchmarking between institutions, aligning with the Engineers Australia (2013) competency standard 1.2 on QS.

Conclusion

First-year students can find it difficult to see the relevance of mathematics to engineering (Flegg et al. 2012), so there should be close collaboration between these disciplines in the design of curriculum. This project opened the dialogue between the schools on how QS currently are and should be taught, practiced and assessed in the first-year of the BET. In an online questionnaire a staff member from mathematics stated “This project has been informative and highly collegial”; they went on to say that the project had “helped to contextualise and focus much of the discussion between mathematics and other disciplines”. The course QS maps allowed staff teaching into the BET to see a visual representation of how the QS interweave; review assumed knowledge, prerequisites, sequencing and development of skills; easily identify overlaps; examine timing and other issues. The team is looking forward to the continuing positive collegial relationship with the service disciplines to the BET; and would recommend other institutions adopt this process for curriculum review and renewal.

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